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SCREENING AND SELECTION OF CANDIDATE SHEET ALLOYS

Final Report, Part II

by

D. B. Hunter

December 1966

TITANIUM METALS CORPORATION OF AMERICA
233 Broadway
New York, New York

Contract DA-30-069-ORD-3743

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U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172

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ABSTRACT

Research under this contract was divided into four stages: Phase I, a screening of stable beta base alloys using sheet produced from ½ pound ingots; Phase II, the addition of elements to selected stable beta bases to bring about precipitation hardening; Phase III, the evaluation of the most promising of the Phase II alloys, using sheet produced from 30 pound ingots; and Phase IV the evaluation of mill-produced sheet from a 500 pound ingot of the best alloy from Phase III. Phases I to III are covered in this Final Report, Part 2.

Phase I research consisted of addition of eutectoid forming elements Fe, Cr and Mn to bases Ti 17V-3Al, Ti 8Mo-8V-3Al and Ti 15Mo-3Al, to produce stable beta bases. From the 39 alloys so produced, three alloys were selected as being suitable bases for addition of elements designed to bring about precipitation hardening: Ti 17V 10Cr 3Al, Ti-8Mo 8V-7.5Fe-3Al and Ti 15Mo-5Fe-3Al. These alloys did not undergo a strength increase of more than 10% after aging for 8 hours at 900F in the solution treated condition and therefore were regarded as stable

Phase II work consisted of additions of Cu Co, Ni, Si Fe, Be, Si and rare earths to the above bases in increasing amounts to bring about precipitation hardening. However, the fabrication properties of such alloys deteriorated before enough of the above elements could be added to bring about precipitation hardening. As an exception, addition of 0.5 1%Si to Ti 17V 10Cr-3Al followed by water quenching from solution temperatures of around 2000F and aging at 1150 1250F, produced Vickers hardness increases of up to 100 points upon aging without visible microstructural change. Although precipitation hardening of a stable beta alloy was thus achieved, grain growth and embrittlement were encountered because of the high temperatures required to dissolve the silicide.

Because of these findings, Phase III work was redirected toward development of two other types of alloy: a moderate strength stable beta alloy, and a high strength metastable beta alloy hardenable by alpha precipitation. Two stable beta alloys, Ti-17V-10Mn-3Al and Ti-8Mo-8V-6Fe-3Al, and two metastable beta alloys, Ti-17V-4Fe-3Al and Ti 8Mo-8V-2Fe-3Al were evaluated.

However, the stable beta alloys had brittle welds, and work on these was discontinued. They were replaced by "stabilized" alloys, metastable alloys aged at 1100-1200F to suppress the maximum aging response and reach a strength plateau. Four such alloys Ti 8Mo 8V-5Co-3Al, Ti 17V-7.5Co 3Al, Ti-17V 2Fe-2Co 3Al and Ti 8Mo 8V 2Fe 3Al were evaluated in this condition, of which the last was found to be best. This same alloy also proved to be best of the high strength metastable beta candidates. On a basis of smooth and notched tensile properties at room temperature and 600F, creep stability and stress corrosion resistance, Ti 8Mo-8V-2Fe 3Al was selected for mill production and evaluation under Phase IV. (Phase IV is covered by Part 1 of this Final Report.)

INTRODUCTION

This final report has been prepared by personnel of Henderson Technical Laboratories of the Titanium Metals Corporation of America, Henderson, Nevada, covering research and development of beta titanium sheet alloys in accordance with terms of United States Army Contract DA-30-069-ORD-3743 sponsored by the Army Materials Research Agency, Watertown, Massachusetts, and under the technical supervision of Mr. S. V. Arnold.

The original objective of this contracted program was development of a stable beta sheet alloy hardenable by compound precipitation. Part II of the final report, which follows, sets forth (1) the philosophy of this alloy development as it affected screening criteria, (2) the experimental sequence which was followed, (3) results which were obtained in test and evaluation of various candidate alloys, and (4) reasons for selecting metastable alloy Ti-8Mo-8V-2Fe-3Al for further development. Part I of the final report details such further development of this alloy to establish mill processing procedures and provide design data information.

It was also planned that the developmental alloy(s) be (1) amenable to state-of-the-art melting, conversion and fabrication practices and (2) comparable in cost to competitive titanium-based compositions. Accordingly, screening criteria were established for reference throughout the program.

It was desired that any new alloy developed should have a basic ingot cost of not more than about ten percent greater than Ti-13V-11Cr-3Al. This of necessity excluded addition of certain elements which might otherwise have seemed promising additions from the metallurgical standpoint. For example, the systems of Ti with Au, Ag and U, might seem to offer possibilities for inducing precipitation-hardening, but because of the cost of these elements, they were not used. Similarly, all alloys should be meltable by normal techniques, that is by consumable-electrode vacuum-arc double melting without excessive loss of alloying elements by volatilization or formation of high density inclusions.

In all phases of the contact, producibility and fabrication qualities of the alloys were of prime importance. All test compositions were hot rolled to a certain gage (usually 0.080-inch), then given a substantial cold reduction to attain the final gage, (usually 0.050-inch). In this process those alloys which possessed marginal rollability were detected as edge cracking tended to occur. Fabrication properties, such as weldability and bendability, were also evaluated.

Pursuant to the above aims and considerations, this program was divided into four phases. Phase I consisted of a survey of alloy limits necessary to assure a stable beta base composition, using various combinations of beta isomorphous and beta eutectoid elements that reject compound sluggishly. Phase II dealt with the addition of various elements to selected stable beta alloys, with the object of bringing about hardening by compound precipitation. In these first two phases, one-half pound button ingots were employed. Although compound precipitation hardening was achieved in Phase II, it was not found possible to overcome the attendant embrittlement. Phase III effort employing 30-lb. ingots was therefore expanded in scope to develop (1) a work-hardenable (non-heat treatable) stable beta alloy and (2) an improved metastable beta alloy based on the Phase I results. Ultimately, a metastable composition was developed during Phase III, which

BACKGROUND AND PHILOSOPHY OF APPROACH

Commercial alpha beta alloys, such as Ti 6Al-4V, and meta-stable beta alloys, such as Ti 13V-11Cr-3Al, are hardened only by making use of the allotropic transformation, that is, by precipitation of beta from alpha prime, or by rejection of alpha phase from metastable beta. However, thus far no titanium alloys have been developed analogous to the precipitation hardenable stainless steels, or nickel based super alloys which are hardened by coherent precipitation of intermetallic compounds.

Several attempts have been made to develop such a class of titanium alloys, but these have been confined to using commercially pure titanium or complex alpha titanium alloys as base materials. Ti-2Cu is an example of an alloy where hardening has been achieved by taking advantage of the decreasing solubility of Cu in alpha titanium[(1)] and relatively excellent short-time strengths to 1000F have been achieved through additions of Cu to a complexed Ti-Al-Zr base.[(2)] However, these alloys show little promise of displacing either the conventional high strength metastable beta or creep-resistant alpha alloys at higher temperatures.

This program was originally based on the premise that it should be possible to select a relatively strong, ductile and stable solid-solution-strengthened beta titanium base alloy to which selected amounts of eutectoid or compound forming elements could be added so that, on suitable heat-treatment, combinations of strength and useful ductility would be produced by aging at moderate temperatures to promote precipitation hardening.

"Stability" for the base alloy was arbitrarily defined as complete retention of beta in a 2 inch thick plate on cooling in still air from 1350F solution temperature. Such stability was intended to simplify heat treatment by obviating the need to quench from solution temperature.

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(1) M. K. McQuillan, U. S. Patent No. 2,977,261.

(2) R. F. Bur[illegible] and H. Margolin, "Development of Active-Eutectoid [illegible] Alloys", WADC Technical Report 58 328, October 1958.

It was also planned that the developmental alloy(s) be (1) amenable to state-of-the-art melting, conversion and fabrication practices and (2) comparable in cost to competitive titanium-based compositions. Accordingly, screening criteria were established for reference throughout the program.

It was desired that any new alloy developed should have a basic ingot cost of not more than about ten percent greater than Ti-13V-11Cr-3Al. This of necessity excluded addition of certain elements which might otherwise have seemed promising additions from the metallurgical standpoint. For example, the systems of Ti with Au, Ag and U, might seem to offer possibilities for inducing precipitation-hardening, but because of the cost of these elements, they were not used. Similarly, all alloys should be meltable by normal techniques, that is by consumable-electrode vacuum-arc double melting without excessive loss of alloying elements by volatilization or formation of high density inclusions.

In all phases of the contact, producibility and fabrication qualities of the alloys were of prime importance. All test compositions were hot rolled to a certain gage (usually 0.080-inch), then given a substantial cold reduction to attain the final gage, (usually 0.050-inch). In this process those alloys which possessed marginal rollability were detected as edge cracking tended to occur. Fabrication properties, such as weldability and bendability, were also evaluated.

Pursuant to the above aims and considerations, this program was divided into four phases. Phase I consisted of a survey of alloy limits necessary to assure a stable beta base composition, using various combinations of beta isomorphous and beta eutectoid elements that reject compound sluggishly. Phase II dealt with the addition of various elements to selected stable beta alloys, with the object of bringing about hardening by compound precipitation. In these first two phases, one-half pound button ingots were employed. Although compound precipitation hardening was achieved in Phase II, it was not found possible to overcome the attendant embrittlement. Phase III effort employing 30-lb. ingots was therefore expanded in scope to develop (1) a work-hardenable (non-heat treatable) stable beta alloy and (2) an improved metastable beta alloy based on the Phase I results. Ultimately, a metastable composition was developed during Phase III, which

could also be "stabilized" by suitable heat treatment. This composition, Ti-8Mo-8V-2Fe-3Al, was more fully evaluated in Phase IV, which consisted of the conversion of a 500-pound ingot to plate and sheet using standard mill processing, and the evaluation of plate and sheet products. The Phase IV effort is reported in Part I of this final report.

MATERIALS

Major alloying additions of normal purity were used in formulating the experimental base alloys melted during Phase I of this program. The analyses of these additions are listed in Table I.

Standard A.S.T.M. methods of analysis were employed.(1) No analyses of hardening agents, added in Phase II, were performed.

PROCEDURES

Melting

For button melts of 250 gm size, compacts of nominal composition (additions weighed to 0.1 gram) were pressed in a 2 inch circular die, under a 50 ton pressure, from blended alloy components. Compacting pressure was about 31,800 psi. Vanadium was added as a master alloy with aluminum. Inasmuch as aluminum was to be added to each alloy, this method represented a convenient and economical procedure. Molybdenum was added in two ways: (1) as a low melting master alloy with aluminum, and (2) where necessary, as a fine elemental powder. The technical problem of alloying titanium with a material of considerably higher melting point was thus obviated. Otherwise, elemental alloy additions were used.

The compacts were then arc melted under an atmosphere of gettered argon with an inert tungsten electrode on a water cooled copper hearth. Suitable precautions were taken so that button

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(1) American Society for Testing & Materials, ASTM Methods for Chemical Analysis of Metals, Philadelphia. 1964 Edition.

melts were not contaminated with volatile constituents or residues from buttons previously in the furnace. All buttons were turned over and remelted several times in order that each would be homo geneous. Analyses of selected Phase I alloys are given in Table II.

All ingots were vacuum melted by the consumable electrode vacuum arc melting process. For primary melting compacts of blended titanium sponge and alloying material were welded together and consumably melted into a copper heat sink crucible. The primary ingots were then lathe turned, welded together (for ingots of more than 10-pound final weight) and arc melted the second time into a copper crucible. After melting, the ingots were sampled for analyses at top, middle and bottom positions. The average analyses are reported in Table III, but for acceptance all three analyses were taken into consideration.

Fabrication

Buttons used in Phases I and II were hot rolled at 1750F (except where otherwise noted) to 0.080-inch thickness on a two-high Waterbury Farrell rolling mill with roll diameters of 8-inches. Each alloy was reheated to temperature between passes. Upon reaching hot rolled gage, the sheets were allowed to cool and the surfaces were then conditioned by sandblasting and pickling in a solution of 35% HNO_3-5%HF-balance water. Each sheet was then cold rolled to 0.050 inch.

Ingots in the 10-30 pound range (Phase III) were processed by forging at 2,000F to 3"x3"xlength; slices 1-inch thick were then cut from this billet after cropping off ends, and these slices were hot rolled at 1750F into 0.080-inch sheets These sheets were cold rolled to 0.050-inch, with the exception of sheets used in welding studies which were rolled to 0.060-inch. Warm rolling, where required, was done at 500F.

Heat Treatment

All solution treatments up to 1850F and aging treatments were carried out in air in an air recirculating furnace having a tolerance to $\pm$15F. For solution temperatures above 1850F an electric muffle furnace was used. During this contract, three different cooling rates after solution treatment were used: Plate

cool, air cool and water quench. For plate cooling, samples were held between two titanium plates, each plate being 6-inch square and 1-inch thick. About 30 minutes were required for the specimen blank within the sandwich to reach temperature. After holding at temperature for the required time (15 minutes), the assemblage was removed from the furnace and allowed to cool in air on a laboratory rack. After about 20 minutes on the rack, the specimen blanks had cooled to 700F. This cooling rate was used in Phase I to simulate cooling rates to be expected in production of 2-inch plate. Figure 1 illustrates the cooling rate at the center of a 2"x6"x 6" plate observed between 1400-700F, compared with that in the center of a titanium sandwich 6-inch square, 2-inches thick. By suitable control of draft conditions, the specimen cooling rates were readily controllable within the limits shown. Figure 1 represents duplicate runs, and the initial temperatures observed were used to calibrate the furnace temperature controller during subsequent heat treatments.

In air cooling, samples were pulled out of the furnace and allowed to cool in air while lying on an asbestos surface. Samples so cooled were separated on the surface to assist in producing a uniform cooling rate. For air-quenching to a given temperature, which was used on certain alloys in Phase II, after being in one furnace for the desired length of time, samples were pulled out of this furnace and held in air until their color matched that of a second furnace, and they were then inserted into that furnace.

In water quenching, samples were pulled straight out of the furnace into a bucket of cold water.

Mechanical Testing Procedures

For all of Phase I and II work, tensile specimens were machined from sheet blanks 4 inches long and 9/16-inch wide. A drawing of the tensile sample is shown in Figure 2. In Phase I work, samples were cut parallel to the rolling direction, but in all subsequent work, all tensile samples were cut transverse to the rolling direction. For evaluation of ingots in Phase III, a larger tensile specimen of a similar general configuration was used, so that total elongation was measured over a 2-inch gage length.

In preparing a sheet tensile specimen for test, the thickness and width were measured to the nearest 0.001 inch and the

cross sectional area was reported as the minimum product of thickness and width obtainable along the length of the specimen. The gage length of the sheet specimen was then coated with layout dye and markings 0.1-inch apart were lightly scribed along the gage length of the specimen.

With this preparation the specimen was placed in a 60,000 pound Riehle screw-type testing machine. An extensometer was attached and testing proceeded, using a paced strain rate of 0.005-inch per inch per minute through 0.2% offset yield strain. Beyond the yield point, the strain rate was increased to 0.05-inch per inch per minute to rupture. Stress-strain curves were obtained through about 2% total strain. Beyond 2% strain only stress was recorded.

After a specimen was broken, it was carefully fitted together so that measurements of ductility could be obtained.

Local elongation was obtained by determining the percent change in length of the two adjacent scribed spaces which included the fracture. Uniform elongation was calculated from the length change over those four adjoining scribed spaces lying farthest removed in the gage length from the fracture. Total elongation was obtained by determining the percent change in length over all ten spaces or full gage length.

Samples for notch tensile testing were machined to the configuration shown in Figure 3.

Creep stability tests were performed upon samples having the same configuration as Figure 2. Creep tests were carried out in CR 12 Riehle frames. After creep exposure, the amount of deformation was measured by means of a travelling microscope using hardness impressions for reference. Samples were then tensile tested at room temperature.

Impact tests upon sheet samples were carried out using laminated Charpy V samples as shown in Figure 4. Samples of sheet were bolted together at each end, to give the approximate width of a standard Charpy V impact sample, the whole laminate was then machined to a configuration similar to that of a Charpy V sample before testing. For correlation purposes, actual test

values were adjusted to conform with those which would have been obtained from a standard specimen on the basis of relative areas.

Bend tests were performed on samples of sheet generally 3/4-inch wide, and 6-inches long. While the width to length ratio of samples varied, no samples having a sample width of less than ten times sheet gage were used.

Bend and tensile tests upon welded samples were carried out on samples machined to the configurations shown in Figure 5.

Hardness tests were carried out on a standard Vickers hardness machine, using a 10 Kg load. At least three, and normally five, impressions were made on each sample, and the average of these taken for the hardness reading.

Determination of hot rolling pressures was made using a 2-hi Birdsboro Mill with 22-inch face rolls fifteen-inches in diameter. Roll separating force was measured by two SR-4 load cells which have a capacity of 150,000 pounds on each screw. Load results were read from a high speed Sanborn Recorder. Samples of starting gage 0.8-inch were given six passes through the mill, the opening being reduced for each successive pass, mill openings were 0.60, 0.45, 0.30, 0.20, 0.10 and 0.04-inches for passes 1-6 respectively. A mill speed of 200 ft/min. was employed.

For determination of cold rolling pressure tests, samples with a starting gage of 0.13-inch were rolled using a 2-High Stannat Mill with rolls of 8 inches in diameter and 10-inch face. Roll separating force was measured by SR-4 type load cells, signals from which were fed to a high speed recorder. To compensate for slight differences in the starting gage, the initial mill opening was set at 10% below the thickness of the panel to be rolled. A series of four passes was made at this initial setting; the opening was then decreased 0.01-inch and a second series of four passes made. A third and final series was taken after decreasing the mill opening by another 0.01-inch.

Metallography

For metallographic examination, bakelite mounted samples were ground on silicon carbide papers of increasing fineness to

600 grit, and then electropolished at 20 volts using a solution containing 600 mls methanol, 60 mls of perchloric acid, 360 mls butyl cellosolve, and 2 mls of solvent "X". Samples were etched in a solution of 1% HF in saturated oxalic acid.

Density Determinations

These were carried out upon sand blasted and pickled portions of sheet, which were weighed in air and then in deaerated water. A precision balance capable of weighing to 0.1 milligram was employed. The precision of densities obtained this way was better than 0.01 gm/cc.

Oxidation Resistance

In Phase I work, the "total weight loss" method was employed. For this, sheet samples 1-inch square were weighed before testing, then given 2 hours exposure in an open crucible at the selected temperatures; after cooling, samples were sandblasted to remove oxide, then again weighed. Results were determined as grams of weight lost per square centimeter of surface. In subsequent work, to attain more uniform results, the method of "total weight gain" was used. For this, weighed samples were exposed in covered crucibles containing holes to permit access of air, and were again weighed after exposure.

Analytical Techniques

Standard A.S.T.M. methods were used for all analyses of experimental alloy compositions.

Stress Corrosion Tests

These were carried out during Phase III of the contract. Samples 3"x½"wide x gage were bent around a die to produce free bend samples of known radii. These bends ranged from ?T to 9T, depending upon the heat-treatment of the alloys. Samples were then coated with a saturated salt solution, air-dried, then exposed for two hours at 800F in still air. Samples were then removed and the salt washed off with water, and examined under a low power lens; they were then flattened out. During this flattening operation, samples most susceptible to stress-corrosion broke. All samples were then examined again under a

low power lens, and finally sections through the fracture were subjected to metallographic examination.

X-Ray Diffraction Studies

For X-ray examinations carried out in this work, 1-inch square pieces of sheet were given appropriate heat treatments. They were then mounted and polished on a series of silicon carbide papers of increasing fineness and then electropolished using a solution containing 600 mls methanol, 360 mls butyl cellosolve, 60 mls of perchloric acid, and 2 mls of Solvent "X". Samples were X-rayed using a Norelco 12045 diffractometer, employing Cu K α radiation with a nickel filter at 40 KV and 20 Ma, using a special device to rotate the sheet specimens about the sheet normal.

Welding Methods

Weldability tests were first performed upon hand welded specimens, but for all subsequent work, machine-welded samples were used.

Hand-welding was performed using the tungsten arc inert gas shielded process, without filler; argon was used for the inert gas and copper back-up plates were used as a heat sink. All specimens from hand welded blanks were machined, one specimen from each blank; beads were not ground flush with the base metal. Sheet gage was 0.050-inch. Welding was carried out using a current of 60 amps at 10 volts; speed of welding was 8 inches/minute.

Machine welding was carried out using 0.060-inch gage sheet which was welded together, without filler, in a welding machine at a speed of 20 inches/minute. Welding current was 100-150 amps at 9 volts, using an electrode of 2% thoriated tungsten, 3/32-inch diameter, using argon as the inert gas for protection. Welds were ground flush before testing of all tensile samples.

PHASE I: SCREENING BASE ALLOYS

To establish a stable beta base to which subsequent addition of compound forming elements might be made, it was deemed desirable to employ only beta-isomorphous elements which do not form compounds with titanium. However, all such elements are relatively weak beta stabilizers and large amounts would be required. For example, the amounts of Mo, V, Cb and Ta which would be required to retain the beta phase upon water quenching are:(1)

Element	Amount Required (Wt %)	Amount Required (Atomic %)
Mo	11	6
V	15	15
Cb	36	22.5
Ta	40	15

Considerably larger percentages would be required for a beta alloy which would be phase stable upon cooling in air in practical section sizes. This would render such alloys excessively dense.

For the above reasons, the relatively strong beta stabilizing elements Cr, Mn and Fe, which form the beta eutectoid type of phase diagram with titanium, were used in Phase I, in conjunction with Mo and V, singly or together. In addition, all compositions were formulated with 3% Al, since Al tends to suppress the formation of the brittle omega phase in beta titanium alloys. Use of Al also means decreased density, price reductions when Al-V master alloys can be used in formulation, and improved melting assimilation of Mo when added as an Al-Mo master alloy.

Unfortunately, little is known regarding the phase relationships throughout quaternary alloys such as Ti-Mo Cr-Al, or Ti-V Fe Al. Even the ternary diagrams such as Ti-Cr V

(1) DMIC Report No. 136A, "The Effects of Alloying Elements in Titanium".

are not determined. However, from the Ti-Cr-Mo beta surface isotherms shown in Figure 6, it is possible to choose a Mo composition which will allow the formation of $TiCr_2$ through beta eutectoid decomposition at reduced temperatures.(1) By the use of tie lines and analogy with the Ti-Cr-Mo diagram, the beta surface isotherms were constructed for the Ti-Cr-V system, Figure 7. From these figures, Mo and V levels were chosen such that the eutectoid decomposition would occur at about 1000F (550C) so that beta would be retained during air cooling of thick sections. It is not known how the Mn and Fe eutectoid compositions or temperatures move with V and Mo additions, but by analogy with the foregoing, one would expect that the eutectoid temperature would lower and the composition would shift to lower values with increasing V or Mo.

Based on the foregoing, Cr was added to Ti-17V-3Al, Ti-8Mo-8V-3Al and Ti-15Mo-3Al base alloys in 2.5 wt. % increments calculated to bracket the eutectoid compositions and to explore the effect of additions at higher levels. To simplify comparisons, Mn was added in the same amounts. As Fe is known to be a stronger beta stabilizer than either Cr or Mn, it was added in lesser amounts. In this way, Phase I compositions were derived. The resulting alloys were then screened by room temperature tensile testing for marginal stability with respect to hypoeutectoid decomposition to alpha, and hypereutectoid decomposition by compound precipitation.

RESULTS

Processing

In general, alloys were hot rolled to 0.080 inch sheet at 1700F without trouble, though slight edge cracking was noted in alloys of all three bases containing more than 10% Cr. During cold rolling from 0.080 to 0.050 inch more cracking occurred. This was mainly confined to those alloys containing the higher percentages of Fe, Cr and Mn, the severity of cracking being

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(1) Ibid, Page 200.

greatest with Fe and least with Mn. The presence of Mo in the base alloy aggravated this effect. Appearance of the sheet after hot and cold rolling is shown in Figures 8a to 8c. No difficulties were encountered during heat treatment or specimen preparation.

Tensile Properties

Tensile properties of all Phase I alloys are given in Tables IV to VI. All alloys tested were found to be mechanically stable, that is, the yield to ultimate strength ratio was above 0.90, Table VII. Mechanical instability in beta alloys is shown by an extreme ability to work harden, there being in such alloys a large difference between yield and ultimate strengths. This behavior is characteristic of marginally stable beta titanium alloys.

The trends of solution treated yield strengths with composition are summarized in Table VIII. Yield strength generally increased with Mo content in the base materials, although this difference tended to decrease as the amount of Cr, Mn or Fe increased. Fe was the most potent solid-solution strengthener while Cr was the least. This difference corresponds with the relative positions of these elements in the periodic table, the element farthest removed from Ti having the greater strengthening effect.

Table IX gives the ratios of aged to solution treated strength for the Phase I alloys. Those alloys containing the lesser amounts of Fe, Cr and Mn strengthened considerably on aging at 900F for 8 hours. These alloys were not considered further in this phase of the contract as only thermally stable base compositions were sought, and alloys showing a strength increase exceeding 10% of the solution treated strength were arbitrarily classified as thermally unstable.

From evaluation of rolling behavior and tensile test results, the least amount of Fe, Cr or Mn necessary to stabilize the bases, and the most that could be tolerated from a processing standpoint, were determined as follows:

Base Material	Minimum Stabilizing Addition (To Nearest 2.5%)	Maximum Amount For Rollability (To Nearest 2.5%)
Ti-17V-3Al	10.0Cr	12.5Cr
	7.5Mn	10.0Mn
	7.5Fe	7.5Fe
Ti-8Mo-8V-3Al	7.5Cr	10.0Cr
	7.5Mn	10.0Mn
	5.0Fe	7.5Fe
Ti-15Mo-3Al	5.0Cr	10.0Cr
	5.0Mn	10.0Mn
	5.0Fe	5.0Fe

The limits for Fe are rather narrower than for the other two elements. The onset of poor cold-rollability with increasing alloy content may be related to probable changes in transition temperature of the B.C.C. beta structure. Warm rolling instead of cold rolling was found to improve the fabrication properties of marginal alloys.

There was no evidence of precipitation hardening upon aging the hypereutectoid group of alloys. Such alloys, after aging, did not show any marked increase in strength over that of the solutionized material.

Modulus values were estimated from stress-strain curves and are summarized for two conditions of heat treatment in Tables X and XI. In the solution treated condition, the elastic moduli consistently increased with the Mo content of the base, and with additions of beta eutectoid elements. On a direct weight percent basis, Fe exhibited the greatest effect on modulus, and Cr the least. Similar relationships are apparent for the alloys in the aged condition, though the compositional effects are much less pronounced.

Ductility trends with compositional variation are shown in Tables XII and XIII. Total elongation values at first tended to increase with the amount of beta stabilization; then, with further increase in alloying content, fell abruptly to lower values.

Metallography

Metallographic examination of the alloys was undertaken to determine the recrystallization temperature and beta transes for solution treatment purposes. Samples which had been previously hot rolled to 0.080 inch gage, then cold rolled to 0.050 inch gage were used. Figure 9 illustrates extensive slip and elongated grains typical of the as-rolled condition. Occasionally extensive cracking was observed, mostly in alloys containing the greater amounts of alloying elements. Usually, after heat treating for ½-hour at 1250F a precipitate was present in the grain boundaries, as in Figure 10, which gradually dissolved on heating at temperatures of 1450F and above. Recrystallization began at 1350F. Some grain growth was evident in many alloys at 1550F. Exceptions to these generalizations were the 15% Mo alloys containing 12.5 and 15% Mn, in which little precipitate appeared at any temperature. This lack of precipitate may be caused by the sluggish eutectoid reaction of Mn.

Examination revealed that a good correlation existed between the tensile properties and microstructures of these alloys. Figure 11 shows Ti-15Mo-7.5Mn-3Al after solution treatment, and Figure 12 shows the same alloy solution treated and aged. This alloy had a solution treated yield strength of 141 Kpsi, and an aged yield strength of 143 Kpsi, with 25% elongation both before and after aging, and was therefore regarded as stable. The two photomicrographs indicate that little precipitate appeared upon aging. By contrast, Ti-17V-2.5Fe-3Al, a thermally unstable alloy, solution treated had a yield strength of 115 Kpsi with 15% elongation, and an aged yield strength of 185 Kpsi with 6% elongation. Comparison of Figures 13 and 14 shows a darkening of grains after aging in this alloy that is characteristic of alpha precipitation.

Oxidation Studies

These tests were carried out at five temperatures, samples being given two hours exposure. Tests were carried out in open crucibles, using a still air electric furnace and sheet samples 1-inch square. Results were determined as grams of weight lost per square centimeter after sandblasting, and are listed in Table XIV, being shown graphically in Figures

15 to 17. The greatest loss in weight was found among alloys in the 17%V group, and the least among the 15%Mo group. In all cases additions of Cr to these alloys reduced the amount of oxidation.

Density Determinations

Densities of the Phase I alloys ranged from 0.171 to 0.191 lbs/cu. in. and are listed in Table XV.

Analytical Determinations

To check button analyses against target compositions and assure that no unusual formulation difficulties would be encountered in melting of alloys selected for Phase II, selected alloys were analyzed. Results in Table II show that with exceptions of Fe and Mn contents, all values are close to those calculated. Some loss of Mn is normal due to its volatility.

SELECTION OF ALLOYS FOR PHASE II

Selection of the base alloys for Phase II was made on a basis of stability, fabrication and tensile properties, with other factors such as density, ease of melting and cost also taken into account. Using these criteria three alloys were selected from ten most promising alloys (Table XVI):

Ti-8Mo-8V-7.5Fe-3Al
Ti-17V-10Cr-3Al
Ti-15Mo-5Fe-3Al

Each base composition was represented in the three alloys chosen to uncover the relative advantages of each system.

The Ti-8Mo-8V-7.5Fe-3Al alloy had a yield strength of over 160 ksi, total elongation over 20%, a uniform elongation of 10%, density of 0.180 lbs/cu. in., fair oxidation resistance, but borderline cold rollability. Although some cracking of the material did occur during rolling, this was not too serious and the sheet had the smoothly rounded outline characteristic of those alloys with good fabricability. During analysis of the material it was found that the Fe content was

½% higher than planned, which no doubt contributed to the rolling problem. This alloy from the all-around point of view was the best stable alloy developed during Phase I.

Ti-17V-10Cr-3Al had a yield strength of 135 Kpsi, total elongation over 14%, uniform elongation of 10%, good rolling properties, a density similar to Ti-13V-11Cr-3Al (0.175 lbs/cu. in.) and fair oxidation resistance. This alloy, though not having the strength of some of the other alloys in the 17%V group, had greater ductility.

Ti-15Mo-5Fe-3Al had a yield strength of 140 Kpsi, total elongation of almost 20%, uniform elongation of at least 10%, a density of 0.183 lbs/cu. in., and good oxidation resistance. It was judged to be the best representative from the 15% Mo group, having a good combination of strength and uniform elongation (though a lower strength/weight ratio than alloys in the other two groups).

PHASE II - SCREENING POTENTIAL PRECIPITATION-HARDENING STABLE BETA ALLOYS

Selection of Precipitation-Hardening Elements

"Precipitation hardening" as a means of strengthening titanium alloys is presently used in several commercial alloys; well known amongst them are Ti-6Al-4V and Ti-13V-11Cr-3Al. Hardening occurs by precipitation of beta from martensitic alpha, or by rejection of alpha from metastable beta. The purpose of this phase of the contract was to explore a third method of precipitation-hardening: precipitation of an intermetallic compound or a phase other than alpha from a stable beta solid solution.

A literature survey was therefore undertaken of the alloying elements having retrograde solid solubilities in beta Ti. A list of the elements considered, with their atomic size factors, solubilities in alpha and beta titanium, electronegativity, valency, and type of intermetallic compound formed is given in Table XVII. The relationships of the atomic size factors and electronegativities to the solubilities of the elements in alpha and beta titanium are shown graphically in Figures 18 and 19. Also included in the table is the respective cost, in dollars/pound, of each element, and; based on this figure, the maximum amount which could be added without raising the cost of the alloy more than 10%. The figures are relative to the time the study began

Alloying elements may be divided into beta-eutectoid, compound formers, and peritectoid categories. They are considered next under these headings in discussing the reasons for their acceptance or rejection.

Elements Forming Beta Eutectoids

A group of beta eutectoid elements that have extensive beta titanium solubility (but restricted solubility in alpha) are: Cu, Ag, Fe, Cr, Mn, Co, U, Ni, Au, Bi, Pb, and Tl. Cu has a large solubility in beta titanium, with a retrograde beta/Ti_2Cu solvus curve. Cu stabilized beta titanium decomposes actively, that is, beta eutectoidal decomposition kinetics

are quite fast compared with those of Fe or Mn stabilized beta. The premise was made that, if eutectoid decomposition is rapid, then Ti_2Cu ought to be rejected actively and cause hardening as material is aged below the solvus. This element was selected in preference to either Ag and Au on cost grounds. Large amounts of Fe, Cr and Mn were found to cause rollability problems in Phase I without commensurate increases in hardenability. They were therefore not considered further as hardening agents.

U has a high density and is relatively costly. However, Ni and Co are cheap, readily available, and have medium densities. These two elements were also selected for use in Phase II.

The other three elements, Bi, Pb and Tl, were considered unsuitable because of their high volatility. Bi and Tl boil below the melting point of titanium and the boiling point of Pb is only slightly higher.

Elements Forming Compounds

These are elements with limited solubility in both alpha and beta titanium and which form compounds. The rather similar elements Si and Ge form isomorphous compounds Ti_5Si_3 and Ti_5Ge_3. Ge has the greater solubility in Ti, but, on account of its limited availability, was considered to be a less desirable hardening agent than Si. Si has a maximum solubility of about 0.4% in alpha, and about 3% in beta. Both Si and Ge were employed in Phase II work.

Use of the element In was ruled out because of its high price, and the large amount needed for any potential hardening.

The Ti Be system is largely unknown; however, Be lowers the melting point of Ti. On the possibility that a favorable retrograde solvus might exist, Be was also included in the list of hardening agents for Phase II.

Peritectoid Elements

The solubility of the rare earths in Ti is limited, mainly because of their low electronegativity values and relative size factors. The only phases co-existing in the Ti-rare earth phase diagrams are the respective terminal solid solutions. However, because of retrograde solubilities in the beta phase, they were

considered potential hardening agents. Owing to the complexity of the alloys employed in this program, compounds of the rare earths, as with Al, might also form the basis for precipitation hardening. On these grounds, misch metal (a mixture of rare earths high in Ce) was selected for evaluation as a hardening agent, along with pure Nd, which has a higher melting point.

Selection of Levels

The elements selected for use as hardening agents in Phase II were thus Cu, Ni, Co, Si, Ge. Be, misch metal and Nd. To bracket the eutectoid compositions, Cu, Ni and Co were first added to base compositions in quantities of 1, 3 and 5% with later adjustments as required. Si, Ge and Be were first added in lesser amounts: 0.5, 1 and 2% of Si and Be, and 2% or Ge. Misch metal and Nd were added in amounts of 1, 2 and 3% to bracket the minimum beta solubilities.

The above elements were added to the base alloys selected from Phase I: Ti-17V-10Cr-3Al, Ti-8Mo-8V-7.5Fe-3Al, and Ti-15Mo-5Fe-3Al. Ingots weighing some 250 grams each were melted, there being eighty-six resulting alloys.

Rollability Screening of Phase II Alloys

Practical work on Phase II was begun by melting and rolling the above one-half pound ingots to sheet. The ingots were break down rolled at 1750F and hot rolled to 0.080-inch gage, then sand blasted and pickled, and cold rolled to 0.050-inch gage. The initial pass of hot rolling was a 5% or less reduction, and each subsequent pass did not exceed a 10% reduction.

All alloys containing misch metal and Nd, and most of those with Be, cracked up during hot rolling. In addition, all samples containing 5% Ni, Co and Cu, with the exception of Ti-17V-10Cr-3Al-5Cu, also cracked up on rolling. In general, the hot rolling performance of the alloys grew progressively worse with increasing "hardener" as well as Mo content. Results of rolling are given in Table XVIII and examples of the sheet produced are shown in Figures 20 to 23.

Several ways to overcome the hot shortness of the alloys containing misch metal were tried. As the solubility of the rare

earths in the beta phase is alleged to be greater at higher temperatures, an attempt was made to hot roll the alloys at 2100F, but they again cracked on the first pass. The rolling temperature was then lowered to 1400F, below the melting point of Ce (1470F), with no improvement in the results. Nd melts at 1880F, but alloys containing it behaved similarly in rolling. The rare earths were therefore not used further in this project.

Results with alloys containing Be were little better. Reduction of the Be content to 0.1, 0.2 and 0.3% (below the original 0.5 - 2% range) was undertaken, but; with the exception of alloys with the Ti-17V-10Cr-3Al base, cracking again took place on hot rolling. However, small specimens of sheet were salvaged and heat treated to determine any hardening response.

As Phase I results had shown large additions of Fe led to poor rolling characteristics, the Fe and Cr contents of the base alloys were reduced, in the supposition that by so doing the tolerance of the base alloy for Cu, Ni and Co would be increased. The Fe content of Ti-15Mo-5Fe-3Al was reduced to 3 and 2% and that of Ti-8Mo-8V-7.5Fe-3Al, to 5 and 4%. The Cr content of Ti-17V-10Cr-3Al was cut back to 8 and 7%. The "hardener" contents remained the same. Hot rolling performances improved only slightly. Alloys containing Cu showed greater hot rollability than those with Ni or Co.

Several other alloys, which had been hot rolled satisfactorily to 0.080-inch gage, cracked during cold rolling to 0.050-inch gage. Usually the cracks extended inwards from the sides of the sheet. Figure 21 shows examples of sheet, containing equal amounts of Cu, Ni, and Co, which were rated as good, poor and fair rolling quality respectively. Figure 21 also shows typical behavior of alloys containing Be; about 0.3% is the maximum tolerated. Figure 23 is characteristic of alloys containing rare earths; disintegration on the first pass of hot rolling was consistently observed.

In summation of rollability screening tests. sheet produced from eleven alloys was good; fifteen alloys produced fair sheet, and twenty five alloys gave poor sheet. Thirty-five alloys were so hot short as to be unworkable.

The hot shortness of alloys containing Ni, Co, Nd and Be was studied metallographically, Figure 24. Specimens in the

as-rolled condition showed cracks occuring along grain boundaries at which there were fine, almost continuous, networks of second phase in all but the alloys containing Be. These latter alloys evidently contained grain boundary eutectic that caused hot shortness.

Heat Treatment Response of Alloys

Five heat treatments were used in screening aging response of the experimental alloy sheet:

(1) Solution treatment at 1350F for ½ hour, plate cooled, aged at 950F for various times;

(2) Solution treated as above, and aged at 1050F for various times;

(3) Solution treated at 1500F for ½ hour, "plate cooled", aged at 850F for various times;

(4) Solution treated at 1350F for ½ hour, quenched, aged at 950F for various times;

(5) Aged at 850F directly from the cold-rolled condition.

The response of various types of alloys as indicated by hardness* and tensile properties will now be discussed.

Results of the first evaluations are contained in Tables XIX to XXVII. Additions forming beta eutectoids generally suppressed, rather than enhanced, aging response, indicating increased beta stabilization without useful precipitation of compound. Although Cu additions seemed to provide some response, it was not enough to be of interest within the rollability limits. These generalizations seemed to hold for all combinations of heat treatment and for all bases containing beta eutectoid additions.

* Values were obtained with a Vickers hardness tester using a 10 Kg load, as previously described.

At this point, the proportions of beta eutectoid elements in the alloys were increased, in the hope of inducing precipitation hardening. Two main approaches were used: first, increasing Cu at the expense of the non-hardening elements in the base alloys, and second, adding Ni at the expense of Cr. As with the earlier results, increasing Cu degraded rollability, particularly in the presence of Mo, see Table XXVIII. The alloys containing increased Ni content could not be rolled to sheet and no further work was done with these alloys.

Tensile properties were determined for those high Cu alloys which could be rolled to good sheet. Results in Table XXIX show the alloys have low solution treated ductility and, though high strengths were attained by a few compositions on aging, these materials were exceedingly brittle. Metallographic studies showed that alpha precipitation accompanied aging in all alloys. Because of this, and the embrittlement tendency, Cu containing alloys were not pursued further.

At this point, attention turned to the possibility that the active eutectoid elements Ni and Co might produce precipitation hardening in the beta alloys containing only beta eutectoid additions. Preliminary rolling studies of ½ pound ingots proved that hypereutectoid binary alloys containing up to 10Ni or 13Co could be hot rolled to sheet. Five percent of each of Fe and Mn was therefore added to the Ti-Ni and Ti-Co alloys at two levels of Ni and Co to provide increased beta stabilization. The alloys could be hot rolled readily, but cold rolled only with difficulty. Primary compound existed in all hot rolled alloys. After solutionizing the compound, the alloys exhibited the aging responses illustrated in Table XXX.

The Ni containing alloys aged up at least 100 VHN in minutes without a significant metallographic change. Such rapid hardness changes suggest omega formation. In any case, alpha appeared upon overaging. Since eutectic melting also occurred in most alloys at the 1750 or 1850F temperatures required to achieve solution, these alloys were not studied further.

The alloys containing Si did not respond to the heat treatments shown in Tables XIX to XXVII. However, metallographic study showed that not all silicides were dissolved at the solution temperatures employed. Additional ½ pound ingots were therefore prepared to more systematically study the solvus and aging parameters.

The effects of Si additions on the tensile properties of Ti-17V-10Cr-3Al are shown in Table XXXI. Strengths are good and ductility is useful up to at least 0.5% Si.

The aging responses of alloys containing 0.5 and 1% Si are shown in Table XXXII. All silicides were dissolved at the solution temperatures used. An aging response of about 80 VHN was achieved in the 1% Si alloy after quenching and aging at 1050 - 1150F. Since no metallographic changes could be associated with the response, the hardening phenomenon was presumed to be true precipitation hardening.

Silicide hardening, however, seemed to be quite rapid as the data in Table XXXIII shows. Plate cooling, instead of water quenching, from solution temperature caused as-solution-treated hardness to increase 30 VHN with a consequent decrease in aging response.

In any case, the specimens solution treated and quenched from 1950 or 2050F were hopelessly brittle. Since extensive grain growth occurred during solutionizing, the cause of the brittleness was not immediately clear. The next experiments, therefore, studied the aging mechanism as well as the effects of grain growth.

Ti-17V-10Cr-3Al-1Si and the same alloy with Si (as a control) were chosen for the mechanism study. X ray diffraction techniques were used to follow the solutionizing and aging phenomena. The results are given in Table XXXIV. The alloys were solution treated both above and below the silicide solvus illustrated in Figure 25 and aged at 1250F so that any phases coming out would be coarse enough to detect.

The X ray diffraction data confirmed metallographic interpretations of the silicide solvus. Ti_5Si_3 was identified after a 1750F solution treatment, but only beta was present after quenching from 2050F. Aging after a 2050F solution treatment produced both alpha and Ti_5Si_3 diffraction peaks. Aging also caused the beta defraction peaks tobroaden, indicative of lattice strain, and low angle scattering to increase. Lattice strain was the only feature observed in this study that might reduce ductility

The grain growth aspect of the situation was approached in three ways:

(1) By solutionizing at 2050F and down quenching to progressively lower temperatures for times of ½ and 15 minutes, then quench and aging to ambient temperatures. (This was intended to show whether step quench sequence could minimize the embrittlement while maintaining aging response.)

(2) By quenching from 2050F directly off the hot rolls to minimize grain growth.

(3) By varying the solution time so as to minimize grain growth.

Results of these experiments are given in Tables XXXV and XXXVI.

Conclusions derived are that step quenching destroys the silicide contribution to the aging response. The same is true for quenching off the rolls, even though bend tests on as-quenched material implied reasonably fine grain size. Since longer solution times and higher solution temperatures also decreased tensile ductility, see Table XXXVI, grain size undoubtedly contributed substantially to the brittleness, though solid solution of Si and silicide distribution were also important.

In view of the shallow depth of hardening, together with difficulties attending effective solution treatment, Si additions were not pursued further. It should be mentioned again, however, that compound precipitation hardening was achieved in this portion of the contract.

Ge proved to be an ineffective hardener as the data in Table XXXVII shows. The 20-30 VHN increase is assignable entirely to alpha hardening.

The use of Be produced results similar to those from Ge, though their alloying behaviors are quite different. Data shown in Table XXXVIII is also explainable on the basis of alpha hardening. Neither Ge nor Be were studied further.

PHASE II SCREENING OF POTENTIAL NON-AGEABLE STABLE BETA ALLOYS AND AGEABLE METASTABLE BETA ALLOYS

At this point in the program the scope of the contract was expanded to include development of medium strength, formable stable beta alloys as well as conventionally metastable beta alloys ageable by alpha precipitation. The stable beta target was a formable and weldable alloy which would possess a strength ratio of approximately 8 x 10^5 inches as delivered from the mill (thereby obviating problems of heat treatment for the manufacturer). The metastable beta target was an alloy which would:

(1) Be low in strength and readily formable as solution treated;

(2) Age to a strength/density ratio of 1 x 10^6 inches with useable ductility;

(3) Be capable of developing strong and ductile fusion welds and;

(4) Insofar as possible be superior to the commercial metastable beta alloy, Ti-13V-11Cr-3Al.

Toward that end, a number of Phase II alloys displaying stable behavior were tensile tested. Alloys selected were those from which better sheet was produced in rollability screening. Results given in Tables XXXIX to XLI show that quite respectable combinations of strength and ductility were found among the alloys. Exploring the stability of these alloys, by aging for 8 hours at 950F, indicated that many underwent little change in either strength or ductility. Base alloys containing Mn, Fe or Co additions displayed the most attractive properties. Bend tests performed on selected alloys also confirmed that formability of most could be judged excellent, Table XLII even after "aging" at 950F for 8 hours.

Based on the above findings, and additional data obtained in Phase I (Tables IV to XIII), Ti-17V-(10-12)Mn-3Al and Ti-8Mo-8V-(6-7)Fe-3Al were selected for Phase III study. Because certain Phase II alloys containing Co had shown high ductility, further investigation of this additive was planned under Phase III.

Phase I work had also shown that base alloys containing less than about 5% Fe, Cr or Mn displayed a marked aging response after aging for 8 hours at 900F. Several could be aged to strength/weight ratios exceeding $1{,}000{,}000^{-1}$ inches. These alloys were therefore examined with regard to producing an ageable beta alloy hardening by alpha precipitation. It was observed that samples containing Fe showed the greatest amount of ductility consistent with a high aging response. On this basis, Ti 17V (1.5-4)Fe-3Al and Ti-8Mo 8V (1-3)Fe-3Al were selected for Phase III study as ageable beta alloys.

PHASE III - EVALUATION OF STABLE AND METASTABLE BETA SHEET ALLOYS

The foregoing work indicated that the prospects of developing a useful precipitation-hardened stable beta alloy, analogous to the stainless steels, were remote. However, as previously described in the conclusion of the Phase II work, two other types of alloy showed promise: (1) Non hardening stable beta alloys; (2) Metastable beta alloys hardening by means of conventional alpha precipitation. These alloy types were therefore evaluated in Phase III.

In both Phase I and II work, stable beta alloys were developed which possessed reasonable fabrication properties and had strength/weight ratios exceeding 800,000^{-1}. From that work, two stable beta alloy ranges were selected for study: Ti-8Mo-8V-(6-7)Fe-3Al and Ti-17V-(10-12)Mn-3Al. Both compositions gave annealed tensile strengths of 160 Kpsi, YS/UTS ratios of 0.9 or higher, uniform elongations of 10%, and elastic moduli exceeding 16.0×10^{-6} lb/in^2. Optimization of these compositions based on fabrication and tensile properties was planned. Partial or complete substitution of Co for Fe was found to improve uniform elongation in Phase II work, so ostensibly stable beta compositions containing Co, with and without Fe, were also evaluated in Phase III.

Also Phase I alloys containing less than 5% additions of Cr, Mn, or Fe displayed marked strengthening after aging for 8 hours at 900F. Several could be aged to strength/weight ratios exceeding 1,000,000 inch^{-1}. The greatest amount of ductility, consistent with high aging response, was found in those alloys containing small amounts of Fe. Ti-17V-(1.5-4)Fe-3Al and Ti 8Mo-8V-(1-3)Fe-3Al were selected on that basis for Phase III study of metastable alloys. Because of potential ductility improvements, three metastable alloys containing Co were also selected for evaluation.

The evaluation of the stable beta alloys will be discussed first, followed by the metastable, or ageable, alloys.

Stable Beta Sheet Alloys

(a) Optimization of Compositional Range

One half pound button ingots of Ti-8Mo 8V-6Fe-3Al, Ti 8Mo 8V-7Fe-3Al, Ti 17V-11Mn-3Al and Ti-17V-12Mn-3Al were used in this evaluation. Alloys were hot rolled at 1750F to 0.080-inch gage sheet, sandblasted and pickled, then cold rolled to 0.050-inch gage. However, during the cold rolling of Ti-8Mo 8V-6Fe-3Al, edge cracking occurred. The remaining sheet of this composition and all Ti-8Mo 8V 7Fe-3Al sheet were therefore rolled at 250F, which greatly reduced edge cracking. Examples of sheet after cold rolling are shown in Figure 26.

Tensile, bend and impact data were obtained from each alloy; tensile samples were either solution treated (1450F-½hr-AC) or solution treated and aged (1450F-½hr AC+900F 8hrs-AC). Tensile results are listed in Table XLIII. These indicate that increasing the Fe or Mn contents respectively of both alloys by 1% produced an increase in ultimate tensile strength of about 5 Kpsi, with a slightly higher gain in yield strength. No change in strength upon aging was found; however, bend data showed that a drop in the bendability of Ti-17V-12Mn-3Al occurred, Table XLIV. Uniform elongation was erratic in all alloys, but local elongation was 30 - 50%.

Metallographic examination of Ti-17V-(11-12)Mn-3Al did not reveal any microstructural change upon aging, but Ti-8Mo-8V-(6 7) Fe-3Al displayed a thickening of some grain boundaries after aging. Examination of sections through broken bend samples failed to reveal any evidence that this led to intergranular rather than transgranular fracture.

Laminated impact specimens from an experimental alloy sheet were tested in both solution treated (1450F ½hr-AC) and in aged conditions (1450F-½hr-AC+900F-8hrs-AC). The specimen configuration was illustrated in Figure 4; dimensions of the laminate were similar to those of a Charpy V notch impact sample. Actual test values were adjusted to conform with those which would have been obtained from a standard specimen. Samples were tested at -80F, room temperature and 300F. Results of tests are listed in Table XLV.

In both annealed and aged conditions a sharp decline in impact strength with decreasing temperature was found, characteristic of BCC crystal structures. For example, at -80F Ti-17V 11Mn-3Al in the solution treated condition had an impact value of only 2.25 ft/lbs, which rose to 14.75 ft/lbs at room temperature, and to 28 ft/lbs at 300F. Similar results were found on the other three alloys; aging generally decreased impact values. In both groups of alloys, lower impact values at -80F and room temperature resulted with increase in the total beta content of the alloys.

The tensile, bend and impact data thus indicated that the lower percentages of Fe or Mn are preferable. Inasmuch as previous Phase I data indicated that Ti-17V-10Mn-3Al was also a stable composition, this alloy was selected for further study over Ti-17V-11Mn-3Al as a conservative measure.

(b) Evaluation of Ti-8Mo-8V-6Fe-3Al and Ti 17V-10Mn-3Al

Thirty-pound ingots were used to evaluate the properties of these two alloys. Analyses are listed in Table III. Forging to 1½-inch thick slabs was carried out at 2100F. No unusual difficulties were encountered. The slabs were rolled to 0.8-inch thick plate at 2100F, for determination of hot rolling pressures. In this test the commercial Ti-13V-11Cr-3Al composition was used as a control. The techniques used in these tests are described in "Materials and Procedures".

Hot rolling pressures were obtained for all three alloys, using initial rolling temperatures of 2100 and 2250F. Panels were heated for 45 minutes before rolling. Results are given in Table XLVI, and shown graphically in Figure 27. Ti-17V-10Mn-3Al and Ti-8Mo-8V-6Fe-3Al were no more difficult to hot roll at 2100F than Ti-13V-11Cr-3Al, and were somewhat easier to hot roll at 2250F than that alloy.

Cold rolling pressure tests were then made; details of this are also described in the "Materials and Procedures" section. Results are listed in Table XLVII. Both alloys had a similar resistance to cold rolling and both were somewhat more difficult to deform than Ti-13V-11Cr-3Al. This no doubt reflects the higher strengths of these stable beta alloys. Reductions were not as heavy as planned because roll separating forces in several passes exceeded the 300,000 pounds rated capacity of the mill.

Mechanical properties were next determined on the alloys, samples being solution annealed for ½ hour at 1450F. Room temperature and 600F notched tensile properties, and 600F smooth tensile properties, creep stability tests, oxidation characteristics, stress corrosion resistance, and weldability were assessed.

A notched configuration of $K_t = 8$ was used for all notched tensile tests. Results, Table XLVIII, indicate that both alloys had NTS/UTS ratios above unity, and that Ti-17V-10Mn-3Al had slightly higher notch strengths. There was little difference in the 600F tensile properties of the alloys; yield strengths of 106-116 Kpsi were found. Thus about 75% of their room temperature yield strength was retained at 600F, Table XLIX.

Creep stability tests were performed at 600F for 150 hours, using loads of 90% of the yield stress at 600F. Creep deformations of around 0.2% resulted, Table L. After creep exposure, samples were tensile tested at room temperature. Compared to the unexposed specimens there were decreases in both local and uniform elongation accompanied by considerable increases in strength.

Oxidation studies were performed on samples of sheet exposed for 2 hours at 1500F; details of the method employed (total weight gain) are described in "Materials and Procedures". Table LI shows that Ti-17V-10Mn-3Al had the lowest weight gain of the two alloys under these conditions, 0.0104 gms/sq.cm. of sheet surface.

To determine the relative susceptibilities of the two stable beta alloys to stress corrosion, samples of each alloy were subjected to unrestrained bend tests. This method is described under "Materials and Procedures". Results are given in Table LII. Low power optical examination of the broken surfaces revealed that Ti-8Mo-8V-6Fe-3Al was the more resistant alloy.

Welded tensile and bend samples of Ti-17V-10Mn-3Al and Ti-8Mo-8V-6Fe-3Al were prepared using methods described under "Materials and Procedures". Tensile results in Table LIII show that these alloys broke before reaching yield stress. Metallographic examination of the alloys failed to reveal any reason

for this. Excellent bend radii were found with the base metal, but welded samples were also brittle in bending, Table LIV. Weldments aged 500 hours at 650F were also brittle.

This lack of weldability constituted a major impedement to the further development of these stable beta alloys. Work on them was therefore discontinued while efforts continued in other directions.

(c) Use of Co in Stable Beta Sheet Alloys

In the course of earlier work it was found that substitution of an equivalent weight percent of Co for Fe produced ageable beta alloys having annealed yield strengths of up to 150 Kpsi. Because such alloys might be weldable in an overaged or "stabilized" condition, they were evaluated as possible equivalents for stable beta compositions.

Tensile tests of Phase II alloys suggested that use of Co produced good strengths and increased uniform elongation. To further explore this, three alloys of potentially stable beta compositions were formulated as ½ pound button ingots: Ti-17V-7.5Co-3Al, Ti-8Mo-8V-5Co-3Al and Ti-8Mo-8V-4Fe-4Co-3Al. Fabrication to sheet by hot and cold rolling methods identical to those employed for Phase I and II alloys, showed that Ti-8Mo-8V-4Fe-3Al had marginal rollability. Room temperature tensile tests, carried out in both the solution treated and aged conditions, showed that only Ti-8Mo-8V-4Fe-4Co-3Al behaved as a stable beta alloy; the other two alloys displayed strength increases upon aging, Table LV.

Since stability after solution annealing was not achieved in a rollable alloy, attention was turned toward the possibility of overaging these alloys at temperatures sufficiently high to suppress any aging response at potential exposure temperatures. Ti-17V-7.5Co-3Al was used to assess this possibility. Specimens were solution treated 15 minutes at 1350F, air cooled, then aged at 1100F for times of up to 16 hours. Results are shown in Table LVI. Aging at 1100F for 16 hours produced only a 13 point hardness increase that was accompanied by precipitation of coarse alpha phase in the microstructure. In this condition the alloy could behave in a manner similar to an otherwise stable beta composition.

Tensile tests of Ti-17V-7.5Co-3Al solution treated and aged at 1100F for 10 and 30 minutes, and 16 hours, were then made. These results confirm the hardness findings in that there was no significant change in strength after aging for 10 or 30 minutes, and only a small strength increase after aging for 16 hours at 1100F, Table LVI. A sharp rise in uniform elongation upon aging for short times appeared to be a useful feature of the treatment. "Stabilization" was thus established in an alloy at yield strength levels on the order of 150 Kpsi.

This technique was then used on the other Phase III alloys then candidates for selection as high strength metastable beta alloys. Samples of Ti-8Mo-8V-5Co-3Al, Ti-17V-7.5Co-3Al, Ti-8Mo-8V-2Fe-3Al and Ti-17V-2Fe-2Co-3Al were solution treated for 10 minutes at 1500F, air cooled, and then aged at 950, 1000, 1100 and 1250F for 8 hours to determine proper "stabilization" treatments. Minimum bend radii determinations showed that after aging for 8 hours at 1100F, all alloys, except possibly Ti-17V-7.5Co-3Al, could pass a 3T bend, Table LVII. A stabilization treatment of 1100F for 8 hours thus allowed adequate formability. With this encouraging result, additional mechanical property tests were carried out.

Tensile and notched tensile test results listed in Tables LVII to LIX show Ti-17V-7.5Co-3Al and Ti-8Mo-8V-5Co-3Al were the stronger alloys at both room temperature and 600F. However, they had low room temperature NTS/UTS ratios of 0.78 and 0.66 respectively. By contrast, Ti-8Mo-8V-2Fe-3Al and Ti-17V-2Fe-2Co-3Al had somewhat lower smooth tensile strengths, but notch tensile properties ratios of 1.16 and 1.07 at room temperature respectively. At 600F the NTS/UTS ratio of all four alloys exceeded unity. These results are probably indicative of transition behavior in the higher Co alloys.

Creep stability tests, Table LX, showed that the higher Co alloys were rather unstable, judging by ductility retained after 600F-150 hour creep exposures. In sharp contrast, Ti-8Mo-8V-2Fe-3Al and Ti-17V-2Fe-2Co-3Al exhibited good ductility after 150 hours exposure. Ti-8Mo-8V-2Fe-3Al was the only alloy providing good stability after 500 hours exposure. The Co containing alloys were thus not sufficiently promising to be considered for further scale-up. Their instability may well be related to rejection of compound.

The stable beta alloys evaluated in this contract proved quite capable of reaching annealed yield strengths on the order of 150 Kpsi with good ductility, but rollability, weldability and/or stability were not adequate. Since the metastable beta alloy Ti 8Mo 8V-2Fe-3Al could be "stabilized" to exhibit substantially the same strength levels without compromising other properties, the stable beta alloys were not considered for Phase IV evaluation.

The next section discusses the further development of metastable beta alloys.

Metastable Beta Sheet Alloys

(a) Optimization of Composition

In Phase I studies, Ti 17V 2.5Fe 3Al and Ti 8Mo 8V 2.5Fe 3Al gave particularly good combinations of aged strengths and ductility, Tables IV and V. In order to optimize further their Fe content, four alloys, Ti-17V-1.5Fe-3Al, Ti 17V-4Fe-3Al, Ti-8Mo-8V-1Fe-3Al and Ti-8Mo-8V-3Fe-3Al were melted as 30-pound ingots, processed to sheet, and evaluated for aging response by hardness and room temperature tensile tests, Tables LXI and LXII. From these results, Ti 17V 4Fe 3Al gave better aged ductility than did Ti 17V 1.5Fe-3Al and was evaluated further. Higher Fe had slowed aging response of Ti 8Mo-8V-1Fe 3Al, but increased uniform ductility. The Fe level in this alloy was optimized at 2%.(1) Ti-17V-4Fe-3Al and Ti-8Mo-8V-2Fe-3Al were then given more extensive property evaluations.

The effects of various aging times and temperatures on the room temperature tensile properties of each of the selected alloys were then determined. Results, Tables LXIII and LXIV, show that both alloys had solution treated yield strengths of about 120 Kpsi, but that Ti 8Mo 8V-2Fe-3Al had a faster aging response in a given time at all aging temperatures employed

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(1) Results of compositional variations on Ti-8Mo 8V-2Fe-3Al, varying the amount of Fe, Al and O are included in Tables A4 and A5 in the Appendix to the Final Report, Part 1

For example, after aging for 8 hours at 900F, the yield strengths of Ti-8Mo-8V-2Fe-3Al and Ti-17V-4Fe-3Al were 180 and 148 Kpsi respectively. Ti 8Mo-8V-2Fe-3Al also appeared to have somewhat higher uniform elongations at yield strengths of 185 Kpsi and above.

To obtain a correlation between room temperature tensile properties and Vickers hardness of these two alloys, hardness results were obtained from broken tensile specimens and were used to calculate a linear regression line for each alloy. Vickers hardness was plotted as the independent variable, and ultimate tensile strength as the dependent variable*. For Ti 8Mo 8V 2Fe 3Al the relationship between Vickers hardness and ultimate tensile strength was expressed by the following equation:

$$\text{UTS} = (\text{Vickers hardness} \times 613) - 48{,}500;$$

and for Ti-17V-4Fe-3Al:

$$\text{UTS} = (\text{Vickers hardness} \times 621) - 44{,}360,$$

where UTS is given in Kpsi. The slopes of these plots are practically identical, Figures 28 and 29, so that 17 Vickers points are equivalent to 10,000 Kpsi. Confidence limits of 95% were also plotted on Figures 28 and 29; the degree of scatter being much smaller with Ti-8Mo-8V-2Fe-3Al.

Both alloys thus seemed to be contenders for scale-up in Phase IV. However, since Co seemed to promise improved tensile ductility from Phase II studies, the potential of Co was studied in three additional ageable beta alloys melted for that purpose. Toward this end, Co was substituted for Fe in alloys Ti-17V-4Fe 3Al and Ti-8Mo-8V-2Fe-3Al. The alloys were: Ti-17V-7.5Co 3Al, Ti-8Mo-8V-5Co-3Al and Ti-17V 2Fe 2Co-3Al. The first two of these were also evaluated as "stabilized" beta alloys, discussed in the previous section. The above three alloys were evaluated as ageable beta alloys, using hardness data and tensile properties to develop heat treatments. Hardness response to aging is shown

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* The method for calculation is given by Brownlee, "Industrial Experimentation".

in Tables LXV to LXVII. As shown in Tables LXVIII to LXX, partial or complete substitution of Co for Fe did not confirm earlier Phase II results, in that uniform elongation was not improved. Aged tensile properties, however, were generally good. Substitution of Co for Fe increased the aging response, thus suggesting that Co was a weaker beta stabilizer than Fe.

Other generalizations are: (1) aging response becomes more rapid with increasing aging temperature; (2) the strengths of the alloys do not decrease with overaging up to 24 hours; (3) aging temperatures above 900F result in lower fully aged strengths. Ti-17V-2Fe-2Co-3Al, containing less Co, exhibited generally better strength/ductility combinations.

Results of 600F smooth tensile tests, Table LXXI, show that Ti-17V-7.5Co-3Al retained most strength at 600F, and Ti-8Mo-8V-5Co-3Al retained the least. The former displayed a yield strength/density ratio of 1×10^6 inches. Percentages of room temperature yield strength retained at 600F varied from 73 - 88%, depending upon the alloy and heat treatment condition, Table LXXII. The tensile properties of Co containing alloys at this temperature looked rather good in contrast to their room temperature data. Again, this may be due to a type of transition behavior.

Notched tensile tests at room temperature and 600F using a notch configuration of $K_t = 8$, were performed on the five alloys. Results, Table LXXIII, show that in room temperature tests Ti-8Mo-8V-2Fe-3Al and Ti-17V-4Fe-3Al had superior NTS/UTS ratios, varying from 0.72 - 1.01. At 600F, Ti-8Mo-8V-2Fe-3Al was the superior alloy with ratios of 1.10. Evidently, the use of Co tends to increase notch sensitivity in these alloys.

All five alloys were creep stability tested in two aged conditions (900F for 8 or 24 hours). Exposures were 600F for 150 and 500 hours at 90% of the 600F yield stress. Results, Table LXXIV, indicate that, although Ti-8Mo-8V-5Co-3Al had the lowest amounts of creep deformation after either exposure time, it lost ductility after the 500 hour exposure. Ti-8Mo-8V-2Fe-3Al provided the best combination of creep resistance and subsequent ductility. These results confirm earlier results from studies of "stabilized" alloys in the previous section.

Hot salt stress corrosion tests, carried out as described in "Materials and Procedures", indicated that Ti-8Mo-8V-2Fe-3Al and Ti-17V-4Fe-3Al were the most resistant to hot salt stress corrosion, Table LXXV. The results are good enough to establish an order of merit, but cannot be considered quantitative.

Tests for oxidation resistance, Table LXXVI, showed that Ti-8Mo-8V-2Fe-3Al and Ti-8Mo-8V-5Co-3Al had the lowest weight gains after exposure in open crucibles at 1500F for 2 hours. This is consistent with earlier results indicating the Ti-8Mo-8V-3Al base to be more oxidation resistant than the Ti-17V-3Al base.

Room temperature tensile tests were performed on welded specimens of Ti-8Mo-8V-2Fe-3Al, Ti-8Mo-8V-5Co-3Al and Ti-17V-7.5Co-3Al, Table LXXVII. Ti-8Mo-8V-2Fe-3Al displayed a good combination of strength and ductility.

Selection of Ageable Beta Alloy for Phase IV

Pertinent properties of the five candidate alloys have been summarized for easy comparison in Table LXXVIII. Ti-8Mo-8V-2Fe-3Al produced the best all-around combination of properties and was selected for Phase IV scale-up and evaluation. Phase IV consisted of the melting and processing to plate and sheet of a 500-pound ingot of Ti-8Mo-8V-2Fe-3Al, using standard mill production equipment and techniques. Both plate and sheet products were evaluated, not only by tests as described herein, but also by additional techniques to determine such properties as K_{Ic}, notch fatigue life, and a quantitative measure of stress corrosion resistance. Part I of this Final Report covers the Phase IV evaluation of Ti-8Mo-8V-2Fe-3Al.

TABLE I

Analyses of Materials Used in Formulation of Alloys

Material	Al %	V %	Mo %	Fe %	Cr %	Mn %	O %	N %	C %	Si %	Other Elements %
Ti Sponge 117 B.H.N.	------	----	-----	0.085	-----	----	0.072	0.007	0.022	------	99.7Ti, 0.109Cl
Al Shot	99.9*	----	-----	0.01	-----	----	0.005*	0.013	-----	0.27	-----
Mo Powder <40 Micron	------	----	99.8*	0.001*	-----	----	------	-----	0.001*	0.001*	0.003W*, 0.001Ni*
Mo Powder >40 Micron	0.001*	----	97.7	0.016	-----	----	0.044	-----	0.009	------	0.001Sn*, 0.001Co*
Mn Powder -10 Mesh	------	----	-----	-----	-----	99.8	0.178	0.005	0.017	------	-----
Cr Powder -10 Mesh	------	----	-----	0.038*	99.3*	----	0.020*	0.014*	0.022*	0.04*	-----
Fe Nails	------	----	-----	99+*	-----	----	------	------	0.1[illegible]	------	------
V/Al Master Alloy	13.4	84.2	-----	0.34	-----	----	0.181	0.055	0.027	0.34	-----
Mo/Al Master Alloy	52.3	----	47.08	0.17	-----	----	0.059	0.008	0.026	0.14	0.06Ti
Co Powder	------	----	-----	0.02*	-----	---	0.073	-----	0.034*	0.002*	0.001Zr*, 99.7Co*, <0.01W*, 0.02Ni*, 0.003Cu*, 0.034S*
TiO_2 Powder	------	----	-----	------	-----	----	40	-----	-----	------	60Ti

*Suppliers Analysis.

TABLE II

Analyses of Selection Phase I Buttons

Alloy	Heat No.	Cr %	Mo %	V %	Fe %	Mn %	Al %	C %	O %	N %	H %
Ti-17V-10Cr-3Al	T3322	9.75	----	16.9	----	----	3.27	.026	0.119	.024	.0133
Ti-8V-8Mo-7.5Fe-3Al	T3307	----	7.84	8.06	8.0	----	3.27	.022	0.100	.012	.0089
Ti-15Mo-5Fe-3Al	T3315	----	15.0	----	5.8	----	3.06	.026	0.117	.011	.0057
Ti-15Mo-7.5Mn-3Al	T3318	----	15.2	----	----	6.98	2.89	.026	0.144	.011	.0070

TABLE III

Analyses of Ingots Used in Phase III

Ingot #	Ingot Wt. (Lbs.)	Composition	Mo %	V %	Al %	Fe %	Mn %	Co %	O %	N %	C %
V2706	30	Ti-17V-10Mn-3Al	----	16.3	2.72	0.166	9.46	----	0.186	0.024	0.024
V2707	30	Ti-8Mo-8V-6Fe-3Al	8.03	8.24	2.99	5.96	----	----	0.183	0.017	0.025
V2729	30	Ti-17V-4Fe-3Al	----	16.7	3.22	3.91	----	----	0.165	0.025	0.023
V2793	30	Ti-8Mo-8V-2Fe-3Al	7.66	7.88	2.97	1.88	----	----	0.110	0.016	0.025
V2785	10	Ti-7.5Mo-7.5V-1.75Fe-2.5Al-0.10 O	7.17	7.36	2.46	1.72	----	----	0.108	0.019	0.022
V2786	10	Ti-7.5Mo-7.5V-1.75Fe-3.5Al-0.18 O	7.18	7.45	3.47	1.76	----	----	0.212	0.016	0.023
V2787	10	Ti-8.5Mo-8.5V-2.25Fe-2.5Al-0.10 O	7.42	8.08	2.25	2.16	----	----	0.131	0.015	0.025
V2788	10	Ti-8.5Mo-8.5V-2.25Fe-3.5Al-0.18 O	8.03	8.53	3.50	2.24	----	----	0.175	0.014	0.023
V2789	10	Ti-16V-3.6Fe-2.5Al-0.10 O	----	15.5	2.55	3.59	----	----	0.116	0.019	0.025
V2790	10	Ti-16V-3.6Fe-3.5Al-0.18 O	----	16.3	3.41	3.45	----	----	0.172	0.024	0.023
V2791	10	Ti-18V-4.4Fe-2.5Al-0.10 O	----	18.3	2.46	4.37	----	----	0.089	0.022	0.023
V2792	10	Ti-18V-4.4Fe-3.5Al-0.18 O	----	19.0	3.60	[illegible].46	----	----	0.195	0.030	0.035
V2858	30	Ti-17V-2Fe-2Co-3Al	----	16.6	3.13	1.98	----	1.82	0.150	0.024	
V2859	30	Ti-17V-4Fe-3Al	----	17.9	3.19	4.00	----	----	0.113	0.017	
V2860	30	Ti-8Mo-8V-2Fe-3Al	7.87	7.96	3.07	2.15	----	----	0.125	0.016	
V2900	30	Ti-8Mo-8V-5Co-3Al	7.46	8.09	2.87	0.061	----	4.86	0.175	0.015	
V2920	30	Ti-17V-7.5Co-3Al	----	16.95	3.07	0.150	----	7.59	0.123	0.032	
V2966	30	Ti-8Mo-8V-5Co-3Al	8.04	8.26	2.95	0.027	----	4.6	0.105	0.018	
V2967	30	Ti-17V-7.5Co-3Al	----	17.1	2.91	0.125	----	7.09	0.093	0.023	
V297[illegible]	30	Ti-17V-2Fe-2Co-3Al	----	17.15	3.11	2.01	----	1.93	0.111	0.019	

TABLE IV

Room Temperature Sheet Tensile Properties of Cr, Mn and Fe Alloys with Ti-17V-3Al Base Composition

Heat No.	Composition	Heat Treatment(1)	Tensile Properties UTS Kpsi	0.2% YS Kpsi	Local El. %	Unif. El. %	Total El. %(2)	Elastic Modulus 10^{-6}psi
T3320	Ti-17V-5Cr-3Al	1350F-15M-SC	121	115	35	7.5	15	13.5
"	"	"	119	114	25	5	11	13.9(3)
"	"	" +900F-8Hr-AC	186	169	10	2.5	5	16.1
"	"	" "	185	168	5	2.5	3	15.8
T3321	Ti-17V-7.5Cr-3Al	1350F-15M-SC	131	124	25	7.5	15	14.9
"	"	"	130	120	25	12.5	17	14.2
"	"	" +900F-8Hr-AC	153	136	20	5	9	15.9
"	"	" "	152	137	15	7.5	10	15.2
T3322	Ti-17V-10Cr-3Al	1350F-15M-SC	140	131	35	20	25	14.8
"	"	"	138	131	35	17.5	22	15.4
"	"	" +900F-8Hr-AC	145	136	25	7.5	14	17.6
"	"	" "	146	136	35	20	23	15.6
T3495	Ti-17V-12.5Cr-3Al	1350F-15M-SC	158	149	20	12.5	14	16.4
"	"	"	152	148	5	2.5	3	16.0
"	"	" +900F-8Hr-AC	157	150	15	2.5	7	16.8
"	"	" "	161	148	25	12.5	15	16.5
T3496	Ti-17V-15Cr-3Al	1350F-15M-SC	167	160	5	2.5	3	16.9
"	"	"	166	159	5	2.5	3	16.5
"	"	" +900F-8Hr-AC	168	161	5	0	2	16.6
"	"	" "	169	158	10	5	7	16.9
T3326	Ti-17V-5Mn-3Al	1350F-15M-SC	124	122	35	5	13	14.1
"	"	"	126	121	35	7.5	13	14.3
"	"	" +900F-8Hr-AC	185	169	10	2.5	3	16.2(4)
"	"	" "	184	166	10	5	7	15.7
T3327	Ti-17V-7.5Mn-3Al	1350F-15M-SC	138	133	40	5	17	15.6
"	"	"	139	135	35	12.5	20	15.6(3)
"	"	" +900F-8Hr-AC	157	145	15	7.5	10	16.3(5)
"	"	" "	151	140	20	7.5	12	15.3

TABLE IV (Continued)

Heat No.	Composition	Heat Treatment (1)	Tensile Properties: UTS Kpsi	0.2%YS Kpsi	Local El. %	Unif. El. %	Total El. % (2)	Elastic Modulus 10^{-6} psi
T3328	Ti-17V-10Mn-3Al	1350F-15M-SC	152	145	40	7.5	19	15.7(5)
"	"	"	151	145	35	22.5	26	17.0
"	"	" +900F-8Hr-AC	156	149	20	10	16	17.9
"	"	" "	157	148	20	12.5	13	16.2
T3501	Ti-17V-12.5Mn-3Al	1350F-15M-SC	171	168	10	5	6	17.6
"	"	"	171	168	10	2.5	9	17.8
"	"	" +900F-8Hr-AC	179	168	10	5	7	16.9
"	"	" "	180	172	10	5	7	17.2
T3502	Ti-17V-15Mn-3Al	1350F-15M-SC	128	---	0	0	0	17.9
"	"	"	113	---	0	0	0	19.0
"	"	" +900F-8Hr-AC	74	---	0	0	0	17.9
"	"	" "	86	---	0	0	0	----
T3323	Ti-17V-2.5Fe-3Al	1350F-15M-SC	120	114	35	7.5	15	12.2
"	"	"	121	116	35	10	16	13.0
"	"	" +900F-8Hr-AC	197	184	15	5	7	16.2
"	"	" "	201	187	10	2.5	5	16.8
T3324	Ti-17V-5Fe-3Al	1350F-15M-SC	135	132	45	10	21	14.6
"	"	"	133	130	40	7.5	16	14.1
"	"	" +900F-8Hr-AC	180	163	15	5	7	15.7
"	"	" "	186	169	15	5	8	16.2(4)
T3325	Ti-17V-7.5Fe-3Al	1350F-15M-SC	155	152	40	5	15	16.7
"	"	"	154	151	45	7.5	19	16.2
"	"	" +900F-8Hr-AC	162	153	30	7.5	13	15.3
"	"	" "	157	152	30	5	12	16.1(5)

(1) M=minutes; SC=slow (plate)cooled; Hr=hour; AC=air cooled.
(2) Total elongation is % in 1-inch.
(3) Broke on scribe mark.
(4) Broke on extensometer mark.
(5) Broke outside gage length.

TABLE V

Room Temperature Sheet Tensile Properties of Cr, Mn and Fe Alloys with Ti-8Mo-8V-3Al Base Composition

Heat No.	Composition	Heat Treatment (1)	Tensile Properties UTS Kpsi	0.2%YS Kpsi	Local El. %	Unif. El. %	Total El. % (2)	Elastic Modulus 10^{-6}psi
T3302	Ti-8V-8Mo-5Cr-3Al	1350F-15M-SC	127	122	40	15	20	14.4
"	"	"	126	122	35	15	18	14.1
"	"	" +900F-8Hr-AC	164	149	10	2.5	4	14.6
"	"	" "	158	149	5	0	2	15.5 (3)
T3303	Ti-8V-8Mo-7.5Cr-3Al	1350F-15M-SC	131	127	30	5	12	14.9
"	"	"	132	125	25	7.5	13	14.8
"	"	" 900F-8Hr-AC	145	135	15	12.5	13	14.9
"	"	" "	141	132	15	7.5	10	15.8
T3304	Ti-8V-8Mo-10Cr-3Al	1350F-15M-SC	141	134	35	17.5	24	16.2
"	"	"	142	135	40	10	18	15.9
"	"	" +900F-8Hr-AC	151	142	25	7.5	16	15.0 (3)
"	"	" "	147	141	20	12.5	14	16.1
T3497	Ti-8V-8Mo-12.5Cr-3Al	1350F-15M-SC	159	153	15	5	7	16.5
"	"	"	160	154	15	5	7	17.2
"	"	" +900F-8Hr-AC	160	155	10	2.5	5	17.1
"	"	" "	162	156	5	0	2	17.1
T3498	Ti-8V-8Mo-15Cr-3Al	1350F-15M-SC	166	158	5	2.5	3	17.4
"	"	"	167	158	5	0	2	17.2
"	"	" +900F-8Hr-AC	166	166	0	0	0	17.5
"	"	" "	170	163	5	2.5	3	17.1
T3308	Ti-8V-8Mo-5Mn-3Al	1350F-15M-SC	133	130	40	7.5	14	14.9
"	"	"	129	125	25	7.5	15	14.1 (3)
"	"	" +900F-8Hr-AC	159	151	5	2.5	4	15.9
"	"	" "	148	144	5	0	1	15.3 (4)
T3309	Ti-8V-8Mo-7.5Mn-3Al	1350F-15M-SC	139	137	45	20.5	27	16.5
"	"	"	139	138	35	7.5	15	15.8
"	"	" +900F-8Hr-AC	144	139	25	7.5	15	15.6 (3)
"	"	" "	143	140	35	12.5	18	16.1

TABLE V (Continued)

Heat No.	Composition	Heat Treatment(1)	Tensile Properties UTS Kpsi	0.2%YS Kpsi	Local El. %.	Unif. El. %	Total El. %(2)	Elastic Modulus 10^{-6}psi
T3310	Ti-8V-8Mo-10Mn-3Al	1350F-15M-SC	152	151	10	2.5	4	16.9
"	"	"	153	152	35	7.5	15	17.3
"	"	" +900F-8Hr-AC	153	153	35	2.5	14	18.4
"	"	" "	154	154	25	2.5	11	18.0(3)
T3505	Ti-8V-8Mo-12.5Mn-3Al	1350F-15M-SC	114	---	0	0	0	----
"	"	"	110	---	0	0	0	----
"	"	" +900F-8Hr-AC	135	---	0	0	0	17.4
"	"	" "	128	---	0	0	0	18.0
T3504	Ti-8V-8Mo-15Mn-3Al	1350F-15M-SC						(5)
"	"	"						"
"	"	" +900F-8Hr-AC						"
"	"	" "						"
T3305	Ti-8V-8Mo-2.5Fe-3Al	1350F-15M-SC	129	125	20	5	9	12.9
"	"	"	130	125	30	15	19	13.0
"	"	" +900F-8Hr-AC	192	180	5	2.5	4	15.7(3)
"	"	" "	194	183	5	2.5	3	17.0
T3306	Ti-8V-8Mo-5Fe-3Al	1350F-15M-SC	140	138	40	10	20	15.9
"	"	"	142	138	40	17.5	22	14.6
"	"	" +900F-8Hr-AC	154	147	25	15	18	15.7
"	"	" "	150	144	25	7.5	12	15.8
T3307	Ti-8V-8Mo-7.5Fe-3Al	1350F-15M-SC	159	156	40	7.5	15	16.3
"	"	"	159	157	40	20.5	25	15.9
"	"	" +900F-8Hr-AC	163	162	40	17.5	21	16.6
"	"	" "	161	160	40	17.5	24	16.6

(1) M=minutes; SC=slow (plate) cooled; Hr=hour; AC=air cooled.
(2) Total elongation is % in 1-inch.
(3) Broke outside gage length.
(4) Surface flaw in specimen.
(5) Sheet of poor quality - not tested.

TABLE VI

Room Temperature Sheet Tensile Properties of Cr, Mn and Fe Alloys with Ti-15Mo-3Al Base Composition

Heat No.	Composition	Heat Treatment(1)	UTS Kpsi	0.2%YS Kpsi	Local El. %	Unif. El. %	Total El. %(2)	Elastic Modulus 10^{-6} psi
			Tensile Properties					
T3311	Ti-15Mo-5Cr-3Al	1350F-15M-SC	126	123	35	12.5	19	15.2
"	"	"	124	120	35	7.5	17	14.7
"	"	" +900F-8Hr-AC	135	128	35	10	18	15.1
"	"	" "	134	127	35	7.5	15	14.5
T3312	Ti-15Mo-7.5Cr-3Al	1350F-15M-SC	132	129	35	10	20	16.8
"	"	"	132	129	25	10	15	16.2
"	"	" +900F-8Hr-AC	134	130	35	12.5	19	16.1
"	"	" "	135	131	45	22.5	23	16.3
T3313	Ti-15Mo-10Cr-3Al	1350F-15M-SC	146	139	35	12.5	20	16.5
"	"	"	148	142	35	15	21	17.4
"	"	" +900F-8Hr-AC	143	138	35	10	17	16.6
"	"	" "	145	139	35	15	22	16.9
T3499	Ti-15Mo-12.5Cr-3Al	1350F-15M-SC	158	150	15	7.5	10	16.8
"	"	"	161	155	15	10	11	17.1
"	"	" +900F-8Hr-AC	159	153	5	2.5	4	17.0
"	"	" "	159	152	10	7.5	8	17.0
T3500	Ti-15Mo-15Cr-3Al	1350F-15M-SC	165	158	5	2.5	3	17.7
"	"	"	167	160	5	2.5	4	17.7
"	"	" +900F-8Hr-AC	165	159	5	0	2	17.7
"	"	" "	165	160	5	2.5	3	17.9
T3317	Ti-15Mo-5Mn-3Al	1350F-15M-SC	132	130	35	10	19	15.0
"	"	"	132	130	35	7.5	11	15.1
"	"	" +900F-8Hr-AC	148	141	25	7.5	13	18.1
"	"	" "	145	140	25	2.5	13	16.0
T3318	Ti-15Mo-7.5Mn-3Al	1350F-15M-SC	142	141	45	25	30	16.5
"	"	"	143	141	40	12.5	22	16.0
"	"	" +900F-8Hr-AC	144	144	45	15	22	16.5
"	"	" "	142	142	45	20	28	16.5

TABLE VI (Continued)

Heat No.	Composition	Heat Treatment(1)	Tensile Properties UTS Kpsi	0.2%YS Kpsi	Local El. %	Unif. El. %	Total El. %	Elastic Modulus 10^{-6}psi
T3319	Ti-15Mo-15Mn-3Al	1350F-15M-SC	155	154	25	5	16	17.4
"	"	"	160	160	10	7.5	10	18.0
"	"	" +900F-8Hr-AC	155	155	10	5	7	18.1
"	"	" "	153	152	5	0	1	17.2
T3505	Ti-15Mo-12.5Mn-3Al	1350F-15M-SC	62	---	0	0	0	----
"	"	"	11	---	0	0	0	18.5
"	"	" +900F-8Hr-AC	92	---	0	0	0	----
"	"	" "	133	---	0	0	0	18.5
T3506	Ti-15Mo-15Mn-3Al	1350F-15M-SC						(3)
"	"	"						"
"	"	" +900F-8Hr-AC						"
"	"	" "						"
T3314	Ti-15Mo-2.5Fe-3Al	1350F-15M-SC	148	143	30	7.5	13	16.2
"	"	"	145	137	15	7.5	13	14.8
"	"	" +900F-8Hr-AC	200	200	5	0	1	15.7(4)
"	"	" "	201	190	5	0	2	17.1
T3315	Ti-15Mo-5Fe-3Al	1350F-15M-SC	149	147	35	7.5	19	16.6
"	"	"	147	145	40	7.5	18	15.6(4)
"	"	" +900F-8Hr-AC	143	143	45	10	19	15.8
"	"	" "	145	142	45	12.5	23	15.8
T3316	Ti-15Mo-7.5Fe-3Al	1350F-15M-SC	150	(1)	5	0	1	18.1(4)
"	"	"	65	---	5	0	0	18.3
"	"	" +900F-8Hr-AC	74	---	5	0	0	17.6(4)
"	"	" "	76	---	0	0	0	18.2

(1) M=minutes; S.C.=slow (plate) cooled; Hr=hours; AC=air cooled.
(2) Total elongation is % in 1-inch.
(3) Sheet of poor quality - not tested.
(4) Broke outside gage length.

TABLE VII

YIELD TO U.T.S. RATIOS OF ALLOYS IN THE SOLUTION TREATED CONDITION

Eutectoid Addition	Base Composition Ti-17V-3Al	Ti-8Mo-8V-3Al	Ti-15Mo-3Al
5Cr	0.955	0.965	0.975
7.5Cr	0.935	0.960	0.980
10Cr	0.945	0.950	0.955
12.5Cr	0.950	0.955	0.955
15Cr	0.975	0.950	0.915
5Mn	0.975	0.975	0.985
7.5Mn	0.970	0.990	0.990
10Mn	0.965	0.995	0.995
12.5Mn	0.980	-----	-----
15Mn	-----	-----	-----
2.5Fe	0.955	0.965	0.955
5Fe	0.980	0.980	0.985
7.5Fe	0.980	0.995	-----

TABLE VIII

SOLUTION TREATED YIELD STRENGTHS AS A FUNCTION OF COMPOSITION

Eutectoid Addition	Base Composition Ti-17V-3Al Kpsi	Ti-8Mo-8V-3Al Kpsi	Ti-15Mo-3Al Kpsi
5Cr	114	122	121
7.5Cr	122	126	129
10Cr	131	134	140
12.5Cr	148	153	152
15Cr	160	158	159
5Mn	121	127	130
7.5Mn	134	137	141
10Mn	145	151	157
12.5Mn	168	---	---
15Mn	---	---	---
2.5Fe	115	125	140
5Fe	131	138	147
7.5Fe	151	156	---

TABLE IX

AGED TO SOLUTION TREATED STRENGTH RATIOS AS FUNCTIONS OF COMPOSITION

Eutectoid Addition	Base Composition Ti-17V-3Al	Ti-8Mo-8V-3Al	Ti-15Mo-3Al
5Cr	1.47	1.22	1.05
7.5Cr	1.11	1.06	1.01
10Cr	1.04	1.05	1.01
12.5Cr	1.00	1.01	1.00
15Cr	1.00	1.04	1.00
5Mn	1.38	1.14	1.08
7.5Mn	1.06	1.01	1.01
10Mn	1.02	1.01	0.98
12.5Mn	1.05	-	-
15Mn	-	-	-
2.5Fe	1.61	1.45	1.39
5Fe	1.27	1.05	0.97
7.5Fe	1.01	1.03	-

TABLE X

ELASTIC MODULUS VALUES OF THE VARIOUS ALLOYS IN THE SOLUTION TREATED CONDITION(1)

Eutectoid Addition	Base Composition Ti-17V-3Al Kpsi	Ti-8Mo-8V-3Al Kpsi	Ti-15Mo-3Al Kpsi
5Cr	13.7	14.2	14.9
7.5Cr	14.5	14.8	16.5
10Cr	15.1	16.0	16.7
12.5Cr	16.2	16.8	16.9
15Cr	16.7	17.3	17.7
5Mn	14.2	14.5	15.0
7.5Mn	15.6	16.1	16.2
10Mn	16.3	17.1	17.7
12.5Mn	17.7	-	18.5
15Mn	18.5	-	-
2.5Fe	12.6	12.9	15.5
5Fe	14.3	15.3	16.1
7.5Fe	16.4	16.1	18.2

(1) Modulus values expressed as 'E'x10^{-6}psi.

TABLE XI

ELASTIC MODULUS VALUES OF THE VARIOUS ALLOYS IN THE AGED CONDITION(1)

Eutectoid Addition	Base Composition Ti-17V-3Al	Ti-8Mo-8V-3Al	Ti-15Mo-3Al
5Cr	15.9	15.0	14.8
7.5Cr	15.5	15.3	16.2
10Cr	16.6	15.5	16.7
12.5Cr	16.6	17.1	17.0
15Cr	16.7	17.3	17.8
5Mn	15.9	15.6	17.0
7.5Mn	15.8	15.8	16.5
10Mn	16.3	18.2	17.6
12.5MN	17.0	17.7	17.6
15Mn	17.9	-	-
2.5Fe	16.5	16.3	16.4
5Fe	15.9	15.7	15.8
7.5Fe	15.7	16.6	17.9

(1) Modulus values expressed as $'E'x10^{-6}$psi.

TABLE XII

DUPLICATE TOTAL ELONGATION VALUES FOR ALLOYS IN THE SOLUTION TREATED CONDITION*

Eutectoid Addition	Base Composition Ti-17V-3Al %		Ti-8Mo-8V-3Al %		Ti-15Mo-3Al %	
5Cr	11	15	18	20	17	19
7.5Cr	15	17	12	13	15	20
10Cr	22	25	18	24	20	21
12.5Cr	14	3	7	7	10	11
15Cr	3	3	3	2	3	4
5Mn	13	13	14	15	11	19
7 5Mn	17	20	15	27	22	30
10Mn	19	26	4	15	10	16
12.5Mn	6	9	0	0	5	7.5
15Mn	0	0	-	-	-	-
2.5Fe	15	16	9	19	13	13
5Fe	16	21	20	22	18	19
7.5Fe	15	19	15	25	1	0

* Total elongation over 1.00-inch gage length.

TABLE XIII

DUPLICATE TOTAL ELONGATION VALUES FOR PHASE I ALLOYS IN THE SOLUTION-TREATED & AGED CONDITION*

Eutectoid Addition	Base Composition					
	Ti-17V-3Al %		Ti-8Mo-8V-3Al %		Ti-15Mo-3Al %	
5Cr	3	5	2	4	15	18
7.5Cr	9	10	10	13	19	23
10Cr	14	23	14	16	17	22
12.5Cr	7	15	5	2	4	8
15Cr	2	7	0	3	2	3
5Mn	3	7	1	4	13	13
7.5Mn	10	12	15	18	22	28
10Mn	13	16	11	14	1	7
12.5Mn	7	7	0	0	0	0
15Mn	0	0	-	-	-	-
2.5Fe	5	7	3	4	1	9
5Fe	7	8	12	18	19	23
7.5Fe	12	13	21	24	0	0

* Total elongation over a 1.00-inch gage length.

TABLE XIV

OXIDATION RESISTANCE OF SELECTED PHASE I ALLOYS

Heat No.	Alloy	Exposure Temp(°F)	Time (Hrs)	Starting Wt.(Gms)	Wt.After Exposure	Gain (Gms)	Wt.After Sand-Blast (Gms)	Total Wt. Loss (Gms)	Wt. Loss Gms/sq cm
T3303	Ti-8V-8Mo-7.5Cr-3Al	1200	2	4.3582	4.3653	.0071	4.3467	.0115	.00044
"	"	1400	"	4.2386	4.2581	.0195	4.2093	.0293	.00113
"	"	1600	"	4.3287	4.4006	.0719	4.2124	.1163	.0046
"	"	1800	"	4.2453	4.3810	.1357	4.0073	.2380	.0092
"	"	2000	"	4.3792	4.6167	.2375	3.9729	.4063	.0157
T3304	Ti-8V-8Mo-10Cr-3Al	1200	"	4.3396	4.3464	.0068	4.3122	.0274	.00106
"	"	1400	"	4.4532	4.4667	.0135	4.3608	.0924	.00347
"	"	1600	"	4.4732	4.5248	.0516	4.3778	.0954	.00368
"	"	1800	"	4.4904	4.5558	.0654	4.2571	.2333	.009[illegible]
"	"	2000	"	4.3787	4.4987	.1200	3.9726	.4061	.0157
T3306	Ti-8V-8Mo-5Fe-3Al	1200	"	4.4675	4.4771	.0096	4.4427	.0248	.00096
"	"	1400	"	4.3893	4.4256	.0363	4.3350	.0543	.0021
"	"	1600	"	4.3917	4.5293	.1376	4.1075	.2842	.0110
"	"	1800	"	4.3697	4.5438	.1741	3.7446	.6251	.0242
"	"	2000	"	4.3636	4.6808	.3172	1/	--	--
T3307	Ti-8V-8Mo-7.5Fe-3Al	1200	"	4.2410	4.2513	.0103	4.2152	.0258	.0010
"	"	1400	"	4.4261	4.4735	.0474	4.3488	.0773	.00298
"	"	1600	"	4.4692	4.6845	.2153	4.0235	.4457	.0172
"	"	1800	"	4.5596	4.7262	.1666	3.9734	.5862	.0277
"	"	2000	"	4.4539	4.9704	.5165	1/	--	--
T3310	Ti-8V-8Mo-10Mn-3Al	1200	"	4.5269	4.5330	.0061	4.5193	.0076	.00029
"	"	1400	"	4.6384	4.6735	.0351	4.5822	.0562	.00217
"	"	1600	"	4.5414	4.5474	.0060	4.3736	.1678	.0065
"	"	1800	"	4.6594	5.4270	.7676	1/	--	--
"	"	2000	"	4.5950	6.2034	1.6084	1/	--	--
T3311	Ti-15Mo-5Cr-3Al	1200	"	4.2948	4.3005	.0057	4.2717	.0231	.00089
"	"	1400	"	4.2814	4.2944	.0130	4.2209	.0605	.00234
"	"	1600	"	4.1950	4.2217	.0267	4.1536	.0414	.0016
"	"	1800	"	4.2061	4.2446	.0385	3.8847	.3214	.0124
"	"	2000	"	4.3446	4.3670	.0244	4.0270	.3176	.0123

1/ Sample disintegrated in blast.

TABLE XIV (continued)

OXIDATION RESISTANCE OF SELECTED PHASE I ALLOYS

Heat No.	Alloy	Exposure Temp. (°F)	Time (Hrs)	Starting Wt. (Gms)	Wt. After Exposure	G in Gms)	Wt. After Sand-Blast (Gms)	Total Wt. Loss (Gms)	Wt. Loss Gms/sq cm
T3313	Ti-15Mo-10Cr-3Al	1200	2	4.3939	4.3988	.0049	4.3523	.0416	.00162
"	"	1400	"	4.5629	4.5726	.0097	4.5342	.0287	.00111
"	"	1600	"	4.4090	4.4345	.0255	4.3285	.0805	.00312
"	"	1800	"	4.4949	4.4829	2/	4.3179	.1770	.0068
"	"	2000	"	4.4818	4.3802	2/	4.1211	.3607	.0140
T3316	Ti-15Mo-7.5Fe-3Al	1200	"	4.6139	4.6186	.0047	4.5648	.0491	.0019
"	"	1400	"	4.5952	4.6144	.0192	4.4894	.1058	.0042
"	"	1600	"	4.5306	4.5805	.0499	4.3637	.1669	.0069
"	"	1800	"	4.8792	4.9325	.0533	1/	--	--
"	"	2000	"	4.6644	5.1011	.4367	1/	--	--
T3317	Ti-15Mo-5Mn-3Al	1200	"	4.3180	4.3241	.0061	4.3045	.0135	.00052
"	"	1400	"	4.2465	4.2679	.0214	4.2153	.0312	.00121
"	"	1600	"	4.3009	4.3587	.0578	4.2048	.0961	.00372
"	"	1800	"	4.2779	4.2752	2/	4.0701	.2078	.0080
"	"	2000	"	4.1796	4.3467	.1671	1/	--	--
T3319	Ti-15Mo-10Mn-3Al	1200	"	4.6372	4.6423	.0051	4.6088	.0284	.00110
"	"	1400	"	4.5986	4.6136	.0150	4.5604	.0382	.00148
"	"	1600	"	4.6246	4.6311	.0065	4.5664	.0582	.00225
"	"	1800	"	4.5457	4.5917	.0460	4.3972	.1945	.0075
"	"	2000	"	4.5692	4.8703	.3011	1/	--	--
T3321	Ti-17V-7.5Cr-3Al	1200	"	4.0367	4.0517	.0150	4.0066	.0301	.00116
"	"	1400	"	4.1451	4.1920	.0469	4.0527	.0924	.00357
"	"	1600	"	4.1901	4.3277	.1376	3.9690	.2211	.0085
"	"	1800	"	4.0351	4.2509	.2158	3.5392	.4959	.0192
"	"	2000	"	4.1486	--	--	3.7615	.3871	.0150
T3322	Ti-17V-10Cr-3Al	1200	"	4.2962	4.3051	.0089	4.2411	.0551	.00213
"	"	1400	"	4.3923	4.4212	.0289	4.3142	.0781	.00302
"	"	1600	"	4.3789	4.4754	.0965	4.1977	.1812	.0070
"	"	1800	"	4.3314	4.4466	.1152	3.8948	.4366	.0169
"	"	2000	"	4.1727	4.0098	2/	3.8915	.2812	.0158

1/ Sample disintegrated in blast.
2/ Oxide lost due to draft.

TABLE XIV (continued)

OXIDATION RESISTANCE OF SELECTED PHASE I ALLOYS

Heat No.	Alloy	Exposure Temp(°F)	Time (Hrs)	Starting Wt.(Gms)	Wt.After Exposure	Gain (Gms)	Wt.After Sand-Blast (Gms)	Total Wt. Loss (Gms)	Wt. Loss Gms/sq cm
T3325	Ti-17V-7.5Fe-3Al	1200	2	4.3503	4.3635	.0132	4.3296	.0721	.00279
"	"	1400	"	4.3270	4.3991	.0721	4.1160	.2110	.0082
"	"	1600	"	4.2825	4.7492	.4667	1/	--	--
"	"	1800	"	4.3445	5.3271	.9826	1/	--	--
		2000	"	4.2360	4.7785	.5425	3.5003	.7357	.0285
T3327	Ti-17V-7.5Mn-3Al	1200	"	4.1412	4.1509	.0097	4.1321	.0091	.00035
"	"	1400	"	4.1911	4.2937	.1026	4.0701	.1210	.00468
"	"	1600	"	4.0510	4.3271	.2761	3.5961	.4549	.0176
"	"	1800	"	4.1770	4.4970	.3200	3.3327	.9643	.0365
"	"	2000	"	4.0500	4.5795	.5295	1/	--	--
T3328	Ti-17V-10Mn-3Al	1200	"	4.2581	4.2683	.0102	4.2421	.0160	.00062
"	"	1400	"	4.3394	4.3206	2/	4.2651	.0743	.00277
"	"	1600	"	4.1645	4.3525	.1876	3.7224	.4425	.0171
"	"	1800	"	4.2477	4.4156	.1679	3.6146	.6331	.0245
"	"	2000	"	4.1564	4.3130	.1566	1/	--	--

1/ Sample disintegrated in blast.
2/ Oxide lost due to draft.

TABLE XV

DENSITIES OF SELECTED PHASE I ALLOYS

Heat No.	Alloy	Densities g/cc No. 1	Densities g/cc No. 2	Average Lbs/In^3
T3302	Ti-8Mo-8V-5Cr-3Al	4.879	4.879	0.1763
T3498	" " " 15Cr "	5.100	5.101	0.1843
T3305	" " " 2.5Fe "	4.853	4.851	0.1754
T3307	" " " 7.5Fe "	5.005	5.003	0.1807
T3308	" " " 5Mn "	4.907	4.907	0.1774
T3504	" " " 15Mn "	5.192	5.191	0.1876
T3320	Ti-17V-5Cr-3Al	4.751	4.749	0.1717
T3496	" " 15Cr "	4.974	4.970	0.1794
T3323	" " 2.5Fe "	4.724	4.724	0.1707
T3325	" " 7.5Fe "	4.870	4.869	0.1760
T3326	" " 5Mn "	4.774	4.776	0.1726
T3502	" " 15Mn "	5.048	5.046	0.1823
T3311	Ti-15Mo-5Cr-3Al	5.023	5.023	0.1815
T3500	" " 15Cr "	5.228	5.227	0.1888
T3314	" " 2.5Fe "	4.976	4.974	0.1795
T3316	" " 7.5Fe "	5.143	5.141	0.1858
T3317	" " 5Mn "	5.025	5.023	0.1817
T3502	" " 15Mn "	5.288	5.288	0.1912

Ti-13V-11Cr-3Al - 0.176 lbs/cu.in.

Pure Ti - .163 lbs/cu.in.

TABLE XVI

A COMPARISON OF THE TEN MOST PROMISING ALLOYS FOUND IN PHASE I

Alloy	UTS psi	Yield psi	Uniform Elong. %	Total Elong. %	Rolling Properties	Density Lbs/In^3	Oxidation Resistance
Ti-17V-10Mn-3Al	155	150	10+	12+	Good	0.1774 1/	Fair
Ti-17V-7.5Fe-3Al	160	150	6	12	Fair	0.1760	Fair
Ti-17V-10Cr-3Al	145	135	10	14+	Good	0.1755 1/	Fair
Ti-8Mo-8V-7.5Fe-3Al	160	160	17	20+	Fair	0.1807	Fair
Ti-8Mo-8V-5Fe-3Al	150	145	10	12+	Good	0.1780 1/	Fair
Ti-8Mo-8V-10Cr-3Al	145	140	10	15	Fair	0.1803 1/	Good
Ti-8Mo-8V-10Mn-3Al	150	150	2.5	11+	Good	0.1825 1/	Fair
Ti-15Mo-7.5Mn-3Al	140	140	17	20+	Good	0.1864 1/	Good
Ti-15Mo-5Fe-3Al	145	142	10	21	Good	0.1826 1/	Good
Ti-15Mo-10Cr-3Al	144	139	12	20	Fair	0.1852 1/	Good
Ti-13V-11Cr-3Al							
(annealed)	125	120	--	10	Fair	0.175	Fair
(aged)	190	170	--	4	----	-----	Fair

All above Phase I alloys tested after aging for 8 hours at 900F

1/ Calculated density.

TABLE XVII

PROPERTIES OF POTENTIAL PHASE II HARDENING ELEMENTS

Element	Crystal Structure	Size Factor	Type Alloy System	Chemical Valency	Electro-Negativity	Max. Solubility In Alpha %	Max. Solubility In Beta %	Compound Formula	Compound Type	Hardener Cost($/1b)	Max. % Addition Consistent With Not Raising Cost of Alloy More Than 10%
Ag	F.C.C.	-2.0	A	1	1.9	14	24	Ti_3Ag	F.C.C.	13.3	3.5
Au	F.C.C.	-2.0	A	3	2.4	6.6	42	Ti_3Au	Tetragonal A15	510.0	0.09
Be	C.P.H.	-23.0	A	2	1.5	0.1?	1?	$TiBe_2$	?	62.0	0.82
Bi	Rhombohedral	+23.8	A	3,5	1.9	1.5	33	Ti_3Bi	Tetragonal	2.25	23.1
Ce	F.C.C.	+22.0	C	3	1.1	0.3?	4	None	---	25.0	2.1
Co	C.P.H.	-15.0	A	2	1.8	1	17	Ti_2Co	F.C.C.	1.57	33.6
Cr	B.C.C.	-13.0	A	3	1.6	0.5	100	$TiCr_2$	F.C.C.	1.19	43.8
Cu	F.C.C.	-12.7	A	2	1.9	2.1	17	Ti_2Cu	F.C.C.	0.47	100
Fe	B.C.C.	-13.0	A	3	1.8	0.2	25	TiFe	B.C.C.	0.30	100
Gd	C.P.H.	+22.5	C	3	1.1	0.3?	0.3?	None	---	275.0	0.12
Ge	Diamond Cubic	-5.4	B	4	1.8	4	12	Ti_5Ge_3	Hexagonal	145.0	0.30
In	F.C.T.	+7.0	A	3	1.7	22?	?	Ti_3In	DO19?	18.25	1.56
La	C.P.H.	+28.0	C	3	1.1	2?	?	None	---	270.0	0.19
Mn	Complex Cubic	-7 to -24	A	2,4	1.5	0.4	35	TiMn	Tetragonal	0.37	100
Nd	C.P.H.	+24.5	C	3	1.2	2?	2?	None	---	360.0	0.14
Ni	F.C.C.	-15.0	A	2	1.8	0.2	12	Ti_2Ni	F.C.C.	1.00	52.2
Pb	F.C.C.	+19.0	A	2,4	1.8	16?	45	Ti_4Pb	DO19	0.09	100
Si	Diamond Cubic	-20.5	A	4	1.8	0.5	3	Ti_5Si_3	Hexagonal	1.60	32.6
Tl	C.P.H.	+17.0	A*	4	1.8	>0.5	?	?	?	7.50	6.9
U	Ortho-rhombic	-7.5	A	4,5,6	1.7	3.8	100	TiU_2	Hexagonal	50.00	1.04
Y	C.P.H.	+23.0	C	3	1.3	1.0?	?	None	---	405.00	0.13

Key to types of alloy systems:

- A - Beta-eutectoid
- B - Peritectoid-compound
- C - Peritectoid-element
- * - System unknown; type thought most likely on basis of size factor and position in periodic table

C.P.H. - Close-packed hexagonal
F.C.C. - Face Centered cubic
B.C.C. - Body centered cubic
F.C.T. - Face centered tetragonal

TABLE XVIII

ROLLING PERFORMANCE OF PHASE II ALLOYS

Heat No.	Alloy	Rolling Performance Hot	Rolling Performance Cold
Ti-17V-10Cr-3Al-X Group			
T 3725	Ti-17V-10Cr-3Al	Good	Good
T-3726	Ti 17V 10Cr 3Al-1Cu	Good	Good
T-3727	Ti-17V-10Cr 3Al 3Cu	Good	Good
T 3728	Ti-17V-10Cr-3Al-5Cu	Fair	Fair
T-3729	Ti 17V-10Cr-3Al-1Ni	Good	Good
T-3730	Ti-17V-10Cr-3Al-3Ni	Good	Fair
T-3731	Ti 17V-10Cr 3Al-5Ni	Cracked 2nd Pass	- -
T 3732	Ti 17V-10Cr-3Al-1Co	Good	Fair
T-3733	Ti-17V-10Cr-3Al-3Co	Fair	Fair
T-3734	Ti-17V 10Cr 3Al-5Co	Fair	Poor
T-3735	Ti-17V 10Cr-3Al 0.5Si	Good	Fair
T-3736	Ti-17V-10Cr-3Al 1Si	Good	Fair
T-3737	Ti 17V-10Cr 3Al-2Si	Fair	Fair
T-3738	Ti-17V 10Cr-3Al-0.5Be	Cracked 2nd Pass	----
T-3739	Ti-17V 10Cr-3Al 1Be	Cracked 1st Pass	- -
T-3740	Ti-17V-10Cr-3Al-2Be	Cracked 1st Pass	-- -
T-3741	Ti-17V-10Cr-3Al-1Misch Metal	Cracked 1st Pass	- --
T-3742	Ti 17V-10Cr-3Al 2Misch Metal	Cracked 1st Pass	--
T-3743	Ti 17V-10Cr 3Al 3Misch Metal	Cracked 1st Pass	--
	MODIFICATIONS OF ALLOYS IMMEDIATELY ABOVE		
T 3928	Ti 17V-10Cr-3Al 1Nd	Cracked 1st Pass (1)	--
T 3929	Ti-17V 10Cr-3Al-1Nd	Cracked 1st Pass (2)	----
T 3930	Ti-17V 10Cr 3Al-1Nd	Cracked 1st Pass (3)	---
T 3925	Ti 17V 8Cr-3Al 3Cu	Good	Good
T 3926	Ti 17V 8Cr 3Al-3Ni	Good	Good
T-3927	Ti 17V-8Cr 3Al 3Co	Good	Good
T-3942	Ti 17V-8Cr-3Al 5Cu	Good	Good
T-3943	Ti 17V-7Cr-3Al 5Ni	Poor	Poor
T 3944	Ti-17V-7Cr 3Al 5Co	Good	Fair
T-3945	Ti-17V 10Cr 3Al-0.1Be	Good	Good
T-3946	Ti-17V-10Cr 3Al-0.2Be	Good	Fair
T-3947	Ti-17V 10Cr-3Al 0.3Be	Poor	Poor

(1) Rolled at 1400F
(2) Rolled at 1750F
(3) Rolled at 2100F

TABLE XVIII (Continued)

Heat No	Alloy	Rolling Performance Hot	Rolling Performance Cold
Ti 8Mo 8V-7.5Fe-3Al X Group			
T 3813	Ti-8Mo-8V-7.5Fe 3Al	Good	Fair
T 3814	Ti 8Mo-8V-7 5Fe-3Al 1Cu	Good	Fair
T-3815	Ti-8Mo-8V 7 5Fe-3Al-3Cu	Fair	Poor
T 3816	Ti-8Mo 8V-7 5Fe 3Al-5Cu	Cracked 2nd Pass	
Y 3817	Ti 8Mo 8V 7.5Fe-3Al 1Ni	Good	Poor
T 3818	Ti 8Mo 8V-7 5Fe-3Al 3Ni	Cracked 1st Pass	-
T 3819	Ti-8Mo 8V 7 5Fe 3Al 5Ni	Cracked 1st Pass	
T 3820	Ti 8Mo 8V 7 5Fe 3Al-1Co	Fair	Poor
T-3821	Ti-8Mo 8V-7 5Fe-3Al 3Co	Poor	Poor
T 3822	i-8Mo-8V-7.5Fe 3Al 5Co	Cracked 1st Pass	----
T-3823	Ti-8Mo-8V-7 5Fe-3Al-0.5Si	Good	Poor
T 3824	Ti-8Mo-8V-7.5Fe 3Al-1Si	Good	Poor
T-3825	Ti-8Mo-8V-7.5Fe-3Al-2Si	Fair	Poor
T 3826	Ti 8Mo-8V-7 5Fe-3Al-0.5Be	Cracked 2nd Pass	----
T-3827	Ti-8Mo-8V-7 5Fe-3Al-1Be	Cracked 1st Pass	---
T-3828	Ti-8Mo-8V-7 5Fe-3Al-2Be	Cracked 1st Pass	----
T-3829	Ti-8Mo-8V-7.5Fe-3Al-1Misch Metal	Cracked 1st Pass	---
T-3830	Ti-8Mo 8V-7.5Fe-3Al-2Misch Metal	Cracked 1st Pass	- --
T 3831	Ti-8Mo 8V 7.5Fe 3Al-3Misch Metal	Cracked 1st Pass	- -
MODIFICATIONS OF ALLOYS IMMEDIATELY ABOVE			
T-3932	Ti-8Mo-8V 5Fe-3Al-3Cu	Good	Fair
T 3933	Ti 8Mo-8V-4Fe-3Al-5Cu	Fair	Fair
T-3934	Ti-8Mo-8V 5Fe-3Al-3Ni	Poor	Poor
T-3935	Ti-8Mo-8V-4Fe-3Al-5Ni	Good	Poor
T-3936	Ti-8Mo-8V-5Fe-3Al-3Co	Poor	Poor
T-3937	Ti-8Mo-8V-4Fe-3Al-5Co	Poor	Poor
T 3938	Ti-8Mo-8V-7 5Fe-3Al-0 1Be	Poor	Poor
T 3939	Ti-8Mo-8V-7.5Fe-3Al-0.2Be	Cracked 2nd Pass	----
T-3940	Ti-8Mo-8V-7 5Fe-3Al-0.3Be	Cracked 1st Pass	----
Ti-15Mo-5Fe-3Al X Group			
T-3874	Ti-15Mo-5Fe-3Al	Good	Fair
T-3875	Ti-15Mo-5Fe-3Al-1Cu	Good	Good
T 3876	Ti-15Mo 5Fe-3Al-3Cu	Cracked 2nd Pass	----
T-3877	Ti-15Mo-5Fe-3Al-5Cu	Cracked 1st Pass	----
T-3878	Ti 15Mo-5Fe 3Al-1Ni	Fair	Poor
T 3879	Ti-15Mo 5Fe 3Al 3Ni	Cracked 1st Pass	----
T 3880	Ti-15Mo 5Fe-3Al-5Ni	Cracked 1st Pass	- -

TABLE XVIII (Continued)

Heat No.	Alloy	Rolling Performance Hot	Cold
Ti 15Mo 5Fe-3Al-X Group, Continued			
T 3881	Ti 15Mo-5Fe-3Al 1Co	Fair	Poor
T 3882	Ti 15Mo-5Fe-3Al 3Co	Cracked 1st Pass	- -
T 3883	Ti-15Mo-5Fe-3Al-5Co	Cracked 1st Pass	- --
T-3884	Ti-15Mo 5Fe-3Al-0.5Si	Good	Fair
T-3887	Ti 15Mo 5Fe-3Al-1Si	Good	Poor
T 3886	Ti 15Mo-5Fe-3Al-2Si	Fair	Poor
T-3885	Ti-15Mo-5Fe-3Al-0.5Be	Good	Poor
T-3888	Ti 15Mo-5Fe-3Al-1Be	Cracked 1st Pass	-- -
T-3889	Ti 15Mo-5Fe-3Al-2Be	Cracked 1st Pass	----
T 3890	Ti-15Mo 5Fe 3Al-1Misch Metal	Cracked 1st Pass	- -
T-3891	Ti-15Mo 5Fe 3Al 2Misch Metal	Cracked 1st Pass	-
T 3892	Ti-15Mo 5Fe 3Al 3Misch Metal	Cracked 1st Pass	
MODIFICATIONS OF ALLOYS IMMEDIATELY ABOVE			
T-3951	Ti-15Mo-3Fe-3Al-3Cu	Good	Good
T-3952	Ti 15Mo 2Fe 3Al-5Cu	Poor	Poor
T-3953	Ti 15Mo 3Fe-3Al-3Ni	Poor	Poor
T-3954	Ti 15Mo 2Fe-3Al-5Ni	Cracked 1st Pass	----
T-3955	Ti-15Mo 3Fe-3Al-3Co	Fair	Poor
T-3956	Ti-15Mo 2Fe-3Al-5Co	Fair	Poor
T-3957	Ti-15Mo-5Fe-3Al-0.1Be	Poor	Poor
T-3958	Ti-15Mo-5Fe 3Al-0.3Be	Cracked 2nd Pass	- --

TABLE XIX

AGING RESPONSE OF Ti-17V-10Cr-3Al-X GROUP ALLOYS AGED AT 950F AND 1050F

Alloy	Vickers Hardness After Solution Treatment at 1350F and Aged for Given Hours at 950F					
	0	2	4	8	16	24
Ti-17V-10Cr-3Al	323	325	327	344	361	379
Ti-17V-10Cr-3Al-1Cu	330	334	335	340	357	367
Ti-17V-10Cr-3Al-3Cu	334	335	337	345	346	---
Ti-17V-10Cr-3Al-5Cu	353	355	356	356	376	---
Ti-17V-10Cr-3Al-1Ni	330	327	326	341	362	---
Ti-17V-10Cr-3Al-3Ni	349	348	358	356	361	---
Ti-17V-10Cr-3Al-1Co	334	336	345	350	371	---
Ti-17V-10Cr-3Al-3Co	368	363	362	368	380	---
Ti-17V-10Cr-3Al-0.5Si	346	355	354	361	377	---
Ti-17V-10Cr-3Al-1Si	356	366	371	375	398	407
Ti-17V-10Cr-3Al-2Si	387	385	387	399	420	---
Ti-17V-8Cr-3Al-5Cu	324	326	338	354	389	---
Ti-17V-7Cr-3Al-5Ni	338	327	335	338	338	---
Ti-17V-7Cr-3Al-5Co	353	328	334	349	372	---
Ti-17V-10Cr-3Al-0.1Be	312	317	293	326	351	---
Ti-17V-10Cr-3Al-0.2Be	329	332	319	330	322	---
Ti-17V-10Cr-3Al-0.3Be	308	313	308	313	332	---
Ti-17V-8Cr-3Al-3Cu	271	248	225	247	289	---
Ti-17V-8Cr-3Al-3Ni	314	274	295	311	267	---
Ti-17V-8Cr-3Al-3Co	304	319	273	305	292	---
	Aged at 1050F					
Ti-17V-10Cr-3Al	323	308	321	326	338	349
Ti-17V-10Cr-3Al-1Cu	330	323	325	337	342	353
Ti-17V-10Cr-3Al-1Si	356	358	366	367	380	387

TABLE XX

HARDNESS RESPONSE OF Ti-17V-10Cr-3Al-X GROUP OF ALLOYS AGED AT 850F

Alloy	Vickers Hardness After Solution Treatment at 1500F and Aged for Given Hours at 850F					
	0	2	4	8	16	24
Ti-17V-10Cr-3Al	308	308	307	310	319	326
Ti-17V-10Cr-3Al-1Cu	307	315	314	298	315	322
Ti-17V-10Cr-3Al-3Cu	313	311	312	314	308	318
Ti-17V-10Cr-3Al-5Cu	327	332	329	308	320	338
Ti-17V-10Cr-3Al-1Ni	370	321	325	326	331	345
Ti-17V-10Cr-3Al-3Ni	345	339	344	356	297	343
Ti-17V-10Cr-3Al-1Co	307	293	315	317	311	337
Ti-17V-10Cr-3Al-3Co	329	329	331	332	319	327
Ti-17V-10Cr-3Al-0.5Si	313	289	319	305	307	274
Ti-17V-10Cr-3Al-1Si	385	321	336	309	325	375
Ti-17V-10Cr-3Al-2Si	358	358	349	365	386	380

TABLE XXI

AGING RESPONSE OF Ti-17V-10Cr-3Al GROUP OF ALLOYS, QUENCHED FROM 1350F AND AGED AT 950F, OR AGED WITHOUT SOLUTION TREATMENT AT 850F

Alloy	Vickers Hardness: Quenched and Aged For Given Times, Hours					Vickers Hardness: Aged in As-Rolled Condition For Given Times, Hours				
	0	2	4	8	16	1	2	4	8	16
Ti-17V-10Cr-3Al	309	306	312	327	345	349	383	405	417	437
Ti-17V-10Cr-3Al-1Cu	319	306	312	319	336	348	342	380	459	[illegible]
Ti-17V-10Cr-3Al-3Cu	327	319	312	317	327	363	345	376	387	413
Ti-17V-10Cr-3Al-5Cu	333	336	339	342	370					
Ti-17V-10Cr-3Al-1Ni	317	309	317	327	345	354	357	401	401	[illegible]
Ti-17V-10Cr-3Al-3Ni	339	333	336	339	351	383	366	397	417	[illegible]
Ti-17V-10Cr-3Al-1Co	345	312	319	319	336					
Ti-17V-10Cr-3Al-3Co	345	333	336	342	351					
Ti-17V-10Cr-3Al-0.5Si	336	333	336	348	370					
Ti-17V-10Cr-3Al-1Si	348	345	351	360	387	394	401	421	433	[illegible]
Ti-17V-10Cr-3Al-2Si	366	370	373	383	412					
Ti-17V-8Cr-3Al-3Cu	306	304	314	319	339					
Ti-17V-8Cr-3Al-3Ni	319	319	333	336	363					
Ti-17V-8Cr-3Al-3Co	333	322	319	330	345					
Ti-17V-8Cr-3Al-5Cu	314	317	327	330	366					
Ti-17V-7Cr-3Al-5Ni	344	336	333	333	332					
Ti-17V-7Cr-3Al-5Co	357	356	356	359	380					
Ti-17V-10Cr-3Al-0.1Be	322	318	325	330	345					
Ti-17V-10Cr-3Al-0.2Be	327	329	327	333	342					
Ti-17V-10Cr-3Al-0.3Be	336	330	330	333	342					

TABLE XXII

AGING RESPONSE OF Ti-8Mo-8V-7.5Fe-3Al GROUP OF ALLOYS AGED AT 950F AND 1050F

Alloy	Vickers Hardness After Solution Treatment at 1350F And Aged for Given Hours at 950F				
	0	2	4	8	16
Ti-8Mo-8V-7.5Fe-3Al	358	348	358	361	361
Ti-8Mo-8V-7.5Fe-3Al-1Cu	368	368	370	368	368
Ti-8Mo-8V-7.5Fe-3Al-3Cu	370	385	383	384	386
Ti-8Mo-8V-7.5Fe-3Al-1Ni	373	379	379	377	373
Ti-8Mo-8V-7.5Fe-3Al-1Co	365	368	373	370	372
Ti-8Mo-8V-7.5Fe-3Al-3Co	414	408	400	399	418
Ti-8Mo-8V-7.5Fe-3Al-0.5Si	396	394	393	398	405
Ti-8Mo-8V-7.5Fe-3Al-1Si	413	418	401	407	419
Ti-8Mo-8V-7.5Fe-3Al-2Si	449	444	450	450	441
Ti-8Mo-8V-5Fe-3Al-3Cu	331	340	352	278	285
Ti-8Mo-8V-4Fe-3Al-5Cu	320	336	301	324	374
Ti-8Mo-8V-5Fe-3Al-3Ni	303	338	314	332	357
Ti-8Mo-8V-5Fe-3Al-3Co	315	342	343	326	326
Ti-8Mo-8V-4Fe-3Al-5Co	342	337	345	358	379
Ti-8Mo-8V-7.5Fe-3Al-0.1Be	353	327	347	347	360
	Aged At 1050F				
Ti-8Mo-8V-7.5Fe-3Al	356	356	362	355	358
Ti-8Mo-8V-7.5Fe-3Al-1Cu	356	365	364	360	377
Ti-8Mo-8V-7.5Fe-3Al-1Si	402	401	390	403	410

TABLE XXIII

AGING RESPONSE OF Ti-8Mo-8V-7.5Fe-3Al GROUP OF ALLOYS AGED AT 850F

Alloy	Vickers Hardness After Solution Treatment At 1500F and Aged for Given Hours at 850F					
	0	2	4	8	16	24
Ti-8Mo-8V-7.5Fe-3Al	348	345	341	339	340	343
Ti 8Mo-8V-7.5Fe-1Cu	337	331	353	336	354	307
Ti-8Mo-8V-7.5Fe-3Cu	358	361	363	362	366	368
Ti-8Mo-8V-7.5Fe-1Ni	347	326	326	354	353	352
Ti-8Mo-8V-7.5Fe-1Co	364	347	363	350	354	360
Ti-8Mo-8V-7.5Fe-3Co	390	390	375	385	384	395
Ti-8Mo-8V-7.5Fe-0.5Si	370	369	370	374	377	381
Ti-8Mo-8V-7.5Fe-1Si	392	392	396	376	389	396
Ti-8Mo-8V-7.5Fe-2Si	433	395	410	436	430	378

TABLE XXIV

AGING RESPONSE OF Ti 8Mo 8V 7.5Fe 3Al GROUP OF ALLOYS, QUENCHED FROM 1350F AND AGED AT 950F, OR AGED WITHOUT SOLUTION TREATMENT AT 850F

	VICKERS HARDNESS									
	Quenched and Aged For Given Times, Hours					Aged in As Rolled Condition for Given Times, Hours				
Alloy	0	2	4	8	16	1	2	4	8	16
Ti 8Mo 8V 7.5Fe 3Al	348	345	345	348	351	(1)	387	-	413	446
Ti 8Mo-8V-7.5Fe 3Al 1Cu	354	357	351	348	354	(1)	376	380	376	390
Ti 8Mo-8V 7.5Fe 3Al 3Cu	370	370	373	370	373	405	390	397	390	401
Ti-8Mo-8V-7.5Fe 3Al 1Ni	357	360	360	360	366					
Ti 8Mo 8V 7.5Fe-3Al 1Co	357	360	360	357	363					
Ti 8Mo 8V 7.5Fe 3Al-3Co	380	387	387	387	390					
Ti-8Mo 8V-7.5Fe 3Al 0.5Si	383	380	387	380	394					
Ti 8Mo 8V-7.5Fe-3Al 1Si	390	394	390	390	402					
Ti 8Mo-8V 7.5Fe-3Al 2Si	429	433	417	425	429					
Ti 8Mo 8V 5Fe 3Al 3Cu	348	345	342	357	354					
Ti 8Mo 8V 4Fe 3Al 5Cu	333	342	348	351	397					
Ti 8Mo-8V-5Fe 3Al 3Ni	357	348	351	360	360					
Ti 8Mo 8V 5Fe-3Al 3Co	357	360	357	357	363					
Ti-8Mo 8V 4Fe 3Al 5Co	373	363	370	370	383					
Ti-8Mo 8V 7.5Fe 3Al 0.1Be	357	357	357	354	366					

(1) Material Exhausted.

TABLE XXV

AGING RESPONSE OF Ti-15Mo-5Fe-3Al GROUP OF ALLOYS AGED AT 950F AND 1050F

Alloy	Vickers Hardness After Solution Treatment at 1350F And Aged for Given Hours at 950F				
	0	2	4	8	16
Ti-15Mo-5Fe-3Al	334	333	336	338	336
Ti-15Mo-5Fe-3Al-1Cu	328	339	334	342	344
Ti-15Mo-5Fe-3Al-3Cu	361	358	361	360	366
Ti-15Mo-5Fe-3Al-1Ni	335	342	330	343	343
Ti-15Mo-5Fe-3Al-1Co	338	339	343	351	343
Ti-15Mo-5Fe-3Al-0.5Si	372	372	376	374	384
Ti-15Mo-5Fe-3Al-1Si	373	372	372	382	377
Ti-15Mo-5Fe-3Al-2Si	420	412	408	400	407
Ti-15Mo-5Fe-3Al-0.5Be	371	370	365	368	376
Ti-15Mo-3Fe-3Al-3Cu	283	304	289	302	301
Ti-15Mo-2Fe-3Al-5Cu	306	298	343	335	379
Ti-15Mo-3Fe-3Al-3Ni	296	311	290	319	(1)
Ti-15Mo-3Fe-3Al-3Co	340	328	299	318	356
Ti-15Mo-2Fe-3Al-5Co	326	333	327	313	325
Ti-15Mo-5Fe-3Al-0.1Be	298	306	294	318	312
	Aged at 1050F				
Ti-15Mo-5Fe-3Al	328	327	327	331	353
Ti-15Mo-5Fe-3Al-1Cu	334	343	344	341	348
Ti-15Mo-5Fe-3Al-1Si	389	377	376	379	396
Ti-15Mo-5Fe-3Al-0.5Be	365	367	373	378	376

(1) Sample too cracked for accurate hardness impressions. One impression only taken gave 360 D.P.N.

TABLE XXVI

AGING RESPONSE OF Ti-15Mo-5Fe-3Al GROUP OF ALLOYS AGED AT 850F

Alloy	Vickers Hardness After Solution Treatment at 1500F And Aged for Given Hours at 850F					
	0	2	[illegible]	8	16	24
Ti-15Mo-5Fe-3Al	314	318	314	312	311	316
Ti-15Mo-5Fe-3Al-1Cu	327	330	323	331	332	331
Ti-15Mo-5Fe-3Al-1Ni	328	327	329	325	328	340
Ti-15Mo-5Fe-3Al-1Co	341	341	337	330	331	343
Ti-15Mo-5Fe-3Al-0.5Si	351	345	344	346	343	356
Ti-15Mo-5Fe-3Al-1Si	359	360	363	364	364	366
Ti-15Mo-5Fe-3Al-2Si	395	407	410	395	394	373

TABLE XXVII

AGING RESPONSE OF Ti 15Mo-5Fe 3Al GROUP OF ALLOYS QUENCHED FROM 1350F AND AGED AT 950F, OR AGED WITHOUT SOLUTION TREATMENT AT 850F

Alloy	VICKERS HARDNESS: Quenched and Aged For Given Times, Hours: 0	2	4	8	16	VICKERS HARDNESS: Aged in As Rolled Condition For Given Times, Hours: 1	2	4	8	16
Ti 15Mo 5Fe 3Al	319	314	322	317	327	383	376	425	433	464
Ti 15Mo-5Fe 3Al 1Cu	325	330	327	327	333	362	366	387	383	425
Ti 15Mo 5Fe 3Al 1Ni	333	322	325	333	342	361	366	397	429	464
Ti 15Mo 5Fe 3Al 1Co	342	336	333	336	339					
Ti 15Mo 5Fe-3Al-0.5Si	357	354	357	360	376					
Ti-15Mo-5Fe-3Al-1Si	360	366	366	370	380					
Ti 15Mo-5Fe 3Al-2Si	387	394	390	390	397					
Ti 15Mo-3Fe 3Al 3Cu	321	317	323	325	353					
Ti-15Mo-2Fe-3Al 5Cu	319	324	340	336	424					
Ti-15Mo 3Fe 3Al-3Ni	337	334	332	343	354					
Ti 15Mo-3Fe 3Al 3Co	354	344	343	349	355					
Ti 15Mo-2Fe 3Al 5Co	338	336	339	341	344					
Ti 15Mo 5Fe-3Al 0.1Be	331	324	332	329	342					

TABLE XXVIII

ROLLING PERFORMANCES OF PHASE II ALLOYS WITH HIGHER ADDITIONS OF COPPER OR NICKEL

Composition	Rolling Performance Hot	Rolling Performance Cold
Alloys With Increased Copper Content		
Ti-17V-3Al-5Cu	Good	Good
Ti-17V-3Al-7.5Cu	Good	Good
Ti-17V-3Al-10Cu	Good	Good
Ti-8Mo-8V-3Al-5Cu	Good	Good
Ti-8Mo-8V-3Al-7.5Cu	Good	Good
Ti-8Mo-8V-3Al-10Cu	Poor	Poor
Ti-6Mo-8V-3Al-7.5Fe-3Cu	Good	Poor
Ti-6Mo-8V-3Al-7.5Fe-5Cu	Poor	Poor
Ti-4Mo-4V-3Al-4Fe-5Cu	Good	Fair
Ti-4Mo-4V-3Al-4Fe-7.5Cu	Good	Fair
Ti-4Mo-4V-3Al-4Fe-10Cu	Poor	----(1)
Ti-4Mo-4V-3Al-4Fe-12.5Cu	Unworkable	----
Ti-15Mo-3Al-5Cu	Good	Good
Ti-15Mo-3Al-7.5Cu	Poor	Poor
Ti-15Mo-3Al-10Cu	Unworkable	----
Ti-13Mo-3Al-5Fe-3Cu	Good	Poor
Ti-13Mo-3Al-5Fe-5Cu	Poor	Poor
Ti-11Mo-3Al-5Fe-3Cu	Good	Poor
Ti-11Mo-3Al-5Fe-5Cu	Poor	Poor
Alloys With Increased Nickel Content		
Ti-17V-5Cr-3Al-5Ni	Poor	----(1)
Ti-17V-5Cr-3Al-7.5Ni	Unworkable	----
Ti-17V-5Cr-3Al-10Ni	Unworkable	----
Ti-17V-3Cr-3Al-7.5Ni	Unworkable	----
Ti-17V-3Cr-3Al-10Ni	Unworkable	----
Ti-17V-3Cr-3Al-12.5Ni	Unworkable	----
Ti-17V-2Cr-3Al-10Ni	Unworkable	----
Ti-17V-2Cr-3Al-12.5Ni	Unworkable	----

(1) These two samples were not cold rolled due to their poor condition

TABLE XXIX

TENSILE PROPERTIES OF BASE ALLOYS WITH COPPER ADDITIONS

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. %	Elastic Modulus ($E \times 10^{-6}$ psi)
T-4230	Ti-17V-3Al-5Cu	1350F(15min)Plate Cool	108	103	25	0	6	11.2
"	"	"	107	102	35	0	7	11.2
"	"	" +900F(8hrs)AC	197	---	5	0	0	15.2(1)
"	"	" +900F(8hrs)AC	210	---	5	0	0	14.5
T-4231	Ti-17V-3Al-7.5Cu	1350F(15min)Plate Cool	140	128	10	5.0	7	12.7
"	"	"	140	131	10	0	2	12.3
"	"	" +900F(8hrs)AC	225	217	5	0	0	15.7(1)
"	"	" +900F(8hrs)AC	219	216	0	0	0	15.5(1)
T-4232	Ti-17V-3Al-10Cu	1350F(15min)Plate Cool	159	146	10	2.5	4	13.6
"	"	"	165	150	10	2.5	3	13.6
"	"	" +900F(8hrs)AC	216	---	5	0	0	16.4(1)
"	"	" +900F(8hrs)AC	227	---	5	0	0	15.9(1)
T-4234	Ti-8Mo-8V-3Al-5Cu	1350F(15min)Plate Cool	139	131	25	5.0	11	12.4
"	"	"	138	131	25	5.0	11	12.5
"	"	" +900F(8hrs)AC	224	---	5	0	0	16.3(1)
"	"	" +900F(8hrs)AC	233	231	5	0	0	16.5(1)
T-4235	Ti-8Mo-8V-3Al-7.5Cu	1350F(15min)Plate Cool	161	150	5	2.5	3	13.6(1)
"	"	"	162	150	10	5.0	-	13.6(1)
"	"	" +900F(8hrs)AC	109	---	0	0	0	17.0(1)
"	"	" +900F(8hrs)AC	Sample broke while machining					
T-4227	Ti-15Mo-3Al-5Cu	1350F(15min)Plate Cool	142	137	30	2.5	9	12.9
"	"	"	149	143	25	2.5	11	13.6
"	"	" +900F(8hrs)AC	211	---	5	0	0	15.6(1)
"	"	" +900F(8hrs)AC	136	---	0	0	0	16.9(1)

(1) Broke outside gage length.

TABLE XXX

ROLLING PERFORMANCE AND AGING RESPONSE OF SELECTED HYPEREUTECTOID TITANIUM ALLOYS, SOLUTION TREATED AT 1750F OR 1850F AND AGED AT 900F

Ingot No.	Alloy	Rolling Performance		Solution Treatment	Vickers Hardness, Aged at 900F								
					Minutes				Hours				
		Hot	Cold		0	5	10	30	1	2	4	8	16
T5220	Ti-8Ni-5Fe	Good	Good	1750F(15min)WQ(3)	394	580	576	542	521	489	498	489	485
T5221	Ti-10Ni-5Fe	"	Poor	1850F(15min)WQ(3)	419	566	579	540	539	523	530	501	500
T5222	Ti-8Ni-5Mn	" (1)	"	1750F(15min)WQ(3)	379	582	576	526	511	506	511	465	484
T5223	Ti-10Ni-5Mn	"	Good(2)	1850F(15min)WQ(3)	392	492	524	545	555	536	530	534	530
T5224	Ti-11Co-5Fe	"	" (2)	1850F(15min)WQ	422	486	450	442	422	461	495	481	393
T5225	Ti-13Co-5Fe	"	" (2)	1850F(15min)WQ(3)(4)	458	450	454	456	429	470	492	497	503
T5226	Ti-11Co-5Mn	" (1)	Poor(2)	1750F(15min)WQ(3)	387	385	408	429	484	489	495	478	483
T5227	Ti-13Co-5Mn	"	" (2)	1850F(15min)WQ(3)(4)	414	426	415	435	433	419	466	494	499

(1) Cracked upon stamping identification on sheet.
(2) Samples were "warm rolled" due to heating of rolls.
(3) Melting in alloy.
(4) Primary compound present.

TABLE XXXI

TENSILE RESULTS ON Ti-17V-10Cr-3Al CONTAINING 01% Si IN THREE SOLUTION TREATED AND AGED CONDITIONS

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. % in 1"	Elastic Modulus ($E\times10^{-6}$psi)
T-4802	Ti-17V-10Cr-3Al	1350F(½hr)AC	149	139	25	10.0	16	13.1
"	"	"	148	141	35	10.0	18	----
"	"	1450F(½hr)AC	139	135	50	7.5	19	14.5
"	"	"	141	136	45	12.5	21	14.3
"	"	1550F(½hr)AC	139	135	50	12.5	24	13.4
"	"	"	140	135	50	12.5	25	13.9
"	"	1350F(½hr)AC+950F(8hrs)AC	171	154	10	5.0	7	14.6(1)
"	"	" "	169	151	5	5.0	6	14.6
"	"	1450F(½hr)AC "	159	144	20	5.0	11	14.1
"	"	" "	178	163	25	12.5	14	15.5
"	"	1550F(3/4hr)AC "	159	148	10	5.0	6	14.0
"	"	" "	155	146	15	5.0	5	15.5
T-4803	Ti-17V-10Cr-3Al-0.25Si	1350F(½hr)AC	150	141	35	17.5	21	14.0
"	"	"	152	145	30	10.0	17	14.4
"	"	1450F(½hr)AC	147	142	45	10.0	19	13.4
"	"	"	145	140	40	7.5	15	13.8
"	"	1550F(½hr)AC	146	138	40	10.0	18	14.6
"	"	"	143	140	50	17.5	25	13.1
"	"	1350F(½hr)AC+950F(8hrs)AC	167	152	10	7.5	8	14.6
"	"	" "	165	153	10	2.5	4	15.3
"	"	1450F(½hr)AC "	161	149	10	7.5	8	14.1
"	"	" "	162	148	20	10.0	12	14.2
"	"	1550F(3/4hr)AC "	155	145	10	2.5	6	13.3
"	"	" "	155	142	15	5.0	8	13.7
T-4804	Ti-17V-10Cr-3Al-0.5Si	1350F(½hr)AC	157	147	25	5.0	10	15.5(1)
"	"	"	158	147	30	7.5	12	15.0
"	"	1450F(½hr)AC	154	147	30	7.5	14	14.4
"	"	"	155	146	20	17.5	19	13.5

(1) Broke outside gage length.

TABLE XXXI (Continued)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. % in 1"	Elastic Modulus (Ex10^{-6}psi)
T-4804	Ti-17V-10Cr-3Al-0.5Si	1550F(½hr)AC	152	145	35	10.0	15	13.8
"	"	"	151	144	40	20.0	27	13.6
"	"	1350F(½hr)AC+950F(8hrs)AC	165	149	10	2.5	5	14.3
"	"	" "	166	156	10	5.0	6	14.2
"	"	1450F(½hr)AC "	168	153	15	7.5	9	14.3
"	"	" "	169	153	10	7.5	8	14.9
"	"	1550F(3/4hr)AC+950F(8hrs)AC	163	153	15	5.0	7	12.9
"	"	" "	162	150	10	5.0	7	15.1
T-4805	Ti-17V-10Cr-3Al-0.75Si	1350F(½hr)AC	No stock					
"	"	"	162	152	15	5.0	8	15.2
"	"	1450F(½hr)AC	160	149	15	15.0	16	16.0(1)
"	"	"	158	146	15	7.5	9	14.6
"	"	1550F(½hr)AC	158	146	15	7.5	10	15.8
"	"	"	158	148	10	5.0	7	17.2(1)
"	"	1350F(½hr)AC+950F(8hrs)AC	171	157	5	2.5	4	14.1(1)
"	"	" "	172	159	5	2.5	4	14.4
"	"	1450F(½hr)AC "	---	---	---	---	---	14.7
"	"	" "	172	156	5	5.0	5	14.7
"	"	1550F(3/4hr)AC+950F(8hrs)AC	170	154	5	5.0	7	16.2
"	"	" "	168	154	5	5.0	5	14.6
T-4806	Ti-17V-10Cr-3Al-1Si	1350F(½hr)AC	165	152	20	10.0	13	15.5
"	"	"	165	148	20	10.0	13	13.4
"	"	1450F(½hr)AC	155	143	10	2.5	5	14.0
"	"	"	160	148	10	5.0	6	14.2(1)
"	"	1550F(½hr)AC	160	154	5	0	1	15.0
"	"	"	160	148	15	5.0	9	15.0
"	"	1350F(½hr)AC+950F(8hrs)AC	171	157	10	2.5	4	14.6
"	"	" "	171	157	5	2.5	6	14.9(1)
"	"	1450F(½hr)AC "	166	153	5	2.5	3	15.0
"	"	" "	169	154	5	2.5	4	14.9
"	"	1550F(3/4hr)AC "	158	152	5	0	1	14.7
"	"	" "	159	149	5	2.5	3	14.6

(1) Broke outside gage length.

TABLE XXXII

AGING RESPONSE OF Ti-17V-10Cr-3Al BASE ALLOY CONTAINING 0.5 AND 1.0 PERCENT SILICON ADDITIONS

Ingot No.	Alloy	Aging Temp. °F	Vickers Hardness After Aging									
				Minutes					Hours			
			0	1	3	5	10	30	1	2	4	8
T5014	Ti-17V-10Cr-3Al-0.5Si 1950(30min)WQ	650	328	340	332	325	319	323	325	327	---	---
		850		334	320	335	336	336	340	337	---	---
		950		337	342	345	340	358	356	361	---	---
		1050		344	349	364	358	344	346	365	---	---
		1150		333	357	350	346	356	366	363	---	---
		1250		354	366	369	370	366	371	376	---	---
		1300		316	318	319	315	325	331	327	327	336
		1350		318	313	320	317	319	319	321	321	320
		1400		317	311	313	315	314	310	317	321	320
T5154	Ti-17V-10Cr-3Al-1Si 2050(30min)WQ	650	347	354	352	347	350	348	362	369	---	---
		850		363	367	355	357	370	378	377	---	---
		950		373	380	384	380	398	403	401	---	---
		1050		363	383	390	403	391	404	436	---	---
		1150		386	397	398	427	446	456	461	---	---
		1250		446	452	445	456	459	453	483	---	---
		1300		375	373	379	381	382	388	390	375	380
		1350		362	364	373	382	385	385	391	376	360
		1400		365	365	378	362	369	374	377	362	362

TABLE XXXIII

EFFECT OF SOLUTION TREATMENT AND COOLING RATE ON THE AGING RESPONSE OF Ti-17V-10Cr-3Al(0.5, 1) Si ALLOY

Ingot No.	Alloy	Solution Treatment	Aging Temp. °F	Vickers Hardness After Aging: Minutes 0	1	3	5	10	30	Hours 1	2
T5014	Ti-17V-10Cr-3Al-0.5Si	1950F-½hr-"plate cooled"	650	364	344	321	354	334	346	350	376
"	"	"	850	364	326	357	341	356	373	38	346
"	"	"	1250	364	379	353	401	369	378	365	388
T5154	Ti-17V-10Cr-3Al-1Si	2050F-½hr-"plate cooled"	650	379	382	---	379	364	374	369	377
"	"	"	850	379	385	381	373	376	377	376	384
"	"	"	1250	379	387	387	385	385	398	398	410
T5445	T[illegible]-10Cr-3Al-0.5Si	1950F(10mins)WQ	1250	314	319	318	320	322	330	329	336
"	"	1950F(30mins)WQ	"	315	318	319	318	318	313	327	328
T5155	Ti-17V-10Cr-3Al-1Si	2050F-10mins-WQ	1250	321	353	361	357	362	358	362	359
"	"	1950F-30mins-WQ	"	321	330	346	341	355	349	343	342

TABLE XXXIV

X-RAY DIFFRACTION ANALYSIS OF Ti-17V-10Cr-3Al ALLOY WITH AND WITHOUT 1.0 PERCENT SILICON ADDITION

Ti-17V-10Cr-3Al						Ti-17V-10Cr-3Al-1Si							
T-7765 Quenched from 1750F		T-7763 Quenched from 2050F		T-7764 Quenched from 2050F Aged at 1250F (5 min.)		T-7760 Quenched from 1750F		T-7762 Quenched from 2050F		T-7761 Quenched from 2050F Aged at 1250F (5 min.)			
d Å	I/I_o	d Å	I/I_o	d Å	I/I_o	d Å	I/I_o	d Å	I/I_o	d Å	I/I_o	Phase	Index
				2.5474	4					2.5572	20	α	100
						2.4338	5			2.4285	4	Ti_5Si_3	210
				2.3599	4							~	002
2.2518	100	2.2629	100	2.2467	100	2.2564	100	2.2499	100	2.2464	100	β	110
						2.1483	5			2.1440	5	Ti_5Si_3	300
				1.7323	3					1.7415	9	α	102
1.6019	20	1.5993	90	1.5913	7	1.5978	19	1.5963	7	1.5863	17	β	200
										1.4775	12	α	110
				1.3395	1					1.3462	9	α	103
1.3048	22	1.3057	81	1.2980	8	1.3039	51	1.3017	79	1.2971	39	β	211
				1.2511	1					1.2539	9	α	202
1.1315	7			1.1231	5	1.1283	5	1.1273	5			β	220
		1.0122	6			1.0099	6					β	310
		0.8566	16									β	321

TABLE XXXV

AGING RESPONSE OF Ti-17V-10Cr-3Al-1Si SHEET STEP QUENCHED FROM 2050F OR QUENCHED FROM THE HOT ROLLS

Button No.	Solution Treatment	Vickers Hardness (10 Kg Load) No Age	Vickers Hardness (10 Kg Load) Aged 1250F(5min)
Step-Quenching			
T-5155	2050F(½hr)WQ	358	446
"	2050F(½hr), Transferred to 1950F, Held 30 seconds, WQ	357	404
"	2050F(½hr), Transferred to 1850F, Held 30 seconds, WQ	363	409
"	2050F(½hr), Transferred to 1750F, Held 30 seconds, WQ	369	408
"	2050F(½hr), Transferred to 1650F, Held 30 seconds, WQ	353	401
"	2050F(½hr), Transferred to 1550F, Held 30 seconds, WQ	355	405
"	2050F(½hr), Transferred to 1450F, Held 30 seconds, WQ	353	404
"	2050F(½hr), Transferred to 1950F, Held 15 minutes, WQ	366	418
"	2050F(½hr), Transferred to 1850F, Held 15 minutes, WQ	355	421
"	2050F(½hr), Transferred to 1750F, Held 15 minutes, WQ	353	414
"	2050F(½hr), Transferred to 1650F, Held 15 minutes, WQ	350	402
"	2050F(½hr), Transferred to 1550F, Held 15 minutes, WQ	364	408
"	2050F(½hr), Transferred to 1450F, Held 15 minutes, WQ	357	410

Quenching Off Rolls

T-6008	Processing Treatment	Vickers Hardness (10 Kg Load)	Lowest Bend Radius Obtainable
"	Rolled at 2050F to 0.080-inch, WQ	342	1.5T
"	Rolled at 2050F to 0.080-inch + 1250F(5 min)AC	380	
"	Rolled at 2050F to 0.050-inch, WQ	343	1.0T
"	Rolled at 2050F to 0.050-inch, + 1250F(5min)AC	376	

TABLE XXXVI

EFFECT OF SOLUTION TEMPERATURE AND TIME ON THE TENSILE PROPERTIES OF Ti-17V-10Cr-3Al

Button No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Elongation, % Local	Uniform	Total in 1"	Modulus Ex10-6psi
T-3725	Ti-17V-10Cr-3Al	1350F(½hr)AC	142	130	40	12.5	23	14.2
"	"	1350F(½hr)AC	143	133	35	17.5	21	14.5
T-4990	"	1950F(5min)WQ	135	132	25	2.5	11	13.8
"	"	1950F(5min)WQ	135	134	25	5.0	14	13.6
"	"	1950F(10min)WQ	130	130	15	0	6	14.0 (1)
"	"	1950F(10min)WQ	132	129	10	2.5	5	13.9
"	"	1950F(20min)WQ	123	120	10	0	4	13.5
"	"	1950F(20min)WQ	124	120	10	0	2	13.9
"	"	1950F(30min)WQ	109	107	5	0	1	13.8 (1)
"	"	1950F(30min)WQ	108	106	5	0	1	13.8
"	"	2050F(5min)WQ	106	103	0	0	0	12.9 (1)
"	"	2050F(5min)WQ	110	105	5	0	1	12.8
"	"	2050F(10min)WQ	100	---	---	---	---	11.1 (1)
"	"	2050F(10min)WQ	110	107	0	0	1	14.1
"	"	2050F(20min)WQ	Sample broke in machining					
"	"	2050F(20min)WQ	---	---	---	---	---	10.4
"	"	2050F(30min)WQ	---	---	---	---	---	--- (1)
"	"	2050F(30min)WQ	73	68	0	0	0	14.6

(1) Sample broke outside gage length.

TABLE XXXVII

AGING RESPONSE OF Ti-17V-10Cr-3Al-2Ge ALLOY

Ingot No.	Alloy	Solution Treatment	Aging Temp. °F	Vickers Hardness After Aging: Minutes 0	1	3	5	10	30	Hours 1	2
T-6121	Ti-17V-10Cr-3Al-2Ge	2000F-½hr-WQ	0	354							
"	"	"	850		367	377	377	387	391	371	391
"	"	"	1050		362	364	374	378	397	367	384
"	"	"	1250		341	342	352	359	361	376	366

TABLE XXXVIII

AGING RESPONSE OF Ti-17V-10Cr-3Al-0.2Be ALLOY QUENCHED FROM 2100F AND AGED AT 650, 850 AND 1250F

Ingot No.	Alloy	Heat Treatment	Vickers Hardness After Aging: Minutes 0	1	3	5	10	30	Hours 1	2
T-5228	Ti-17V-10Cr-3Al-0.2Be	2100F(½hr)WQ+650F Age	357	350	342	337	328	338	337	356
"	"	2100F(½hr)WQ+850F Age	357	348	351	350	356	369	354	348
"	"	2100F(½hr)WQ+1250F Age	357	335	365	337	343	343	361	390

TABLE XXXIX

TENSILE PROPERTIES OF Ti-17V-10Cr-3Al-X STABLE BETA SHEET ALLOY CANDIDATES

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. %	Elastic Modulus ($Ex10^{-6}psi$)
T-3725	Ti-17V-10Cr-3Al	1350F(½hr)AC	142	130	40	12.5	23	14.2
"	"	"	143	133	35	17.5	21	14.5
"	"	" +950F(8hrs)AC	160	141	20	10.0	12	15.2
"	"	" "	159	141	20	10.0	13	14.8
T-3726	Ti-17V-10Cr-3Al-1Cu	1350F(½hr)AC	145	134	30	12.5	17	14.8
"	"	"	144	133	30	17.5	19	14.6
"	"	" +950F(8hrs)AC	156	141	20	10.0	13	14.9
"	"	" "	158	140	10	10.0	12	14.9
T-3727	Ti-17V-10Cr-3Al-3Cu	1350F(½hr)AC	148	141	45	17.5	24	14.1
"	"	"	149	140	40	17.5	23	14.5
"	"	" +950F(8hrs)AC	155	144	30	12.5	18	14.9
"	"	" "	156	144	30	10.0	17	15.2
T-3728	Ti-17V-10Cr-3Al-5Cu	1350F(½hr)AC	157	151	40	10.0	20	14.8
"	"	"	158	150	40	12.5	20	14.3
"	"	" +950F(8hrs)AC	162	155	5	2.5	4	14.8
"	"	" "	167	156	10	2.5	5	15.0
T-3729	Ti-17V-10Cr-3Al-1Ni	1350F(½hr)AC	146	137	35	10.0	19	14.8
"	"	"	146	134	35	10.0	18	14.5
"	"	" +950F(8hrs)AC	157	139	25	17.5	18	15.3
"	"	" "	160	139	30	12.5	16	14.5
T-3732	Ti-17V-10Cr-3Al-1Co	1350F(½hr)AC	151	140	35	12.5	21	14.3
"	"	"	150	138	35	12.5	20	14.9
"	"	" +950F(8hrs)AC	157	143	30	12.5	18	15.5
"	"	" "	157	143	25	12.5	18	15.1
T-3925	Ti-17V-8Cr-3Al-3Cu	1350F(½hr)AC	143	133	35	15.0	24	14.0
"	"	"	143	132	35	15.0	21	14.4
"	"	" +950F(8hrs)AC	151	136	0	7.5	8	14.0
"	"	" "	154	138	30	10.0	16	14.1

TABLE XXXIX (Continued)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. %	Elastic Modulus ($Ex10^{-6}$ psi)
T-3926	Ti-17V-8Cr-3Al-3Ni	1350F(½hr)AC	152	142	40	5.0	17	14.3
"	"	"	151	141	40	5.0	16	14.5
"	"	" +950F(8hrs)AC	161	147	25	12.5	17	14.6
"	"	" "	162	147	5	7.5	8	14.4
T-3927	Ti-17V-8Cr-3Al-3Co	1350F(½hr)AC	154	145	45	12.5	24	15.2
"	"	"	155	145	45	12.5	24	15.3
"	"	" +950F(8hrs)AC	159	146	35	12.5	19	15.1
"	"	" "	160	147	20	12.5	15	15.2
T-3942	Ti-17V-8Cr-3Al-5Cu	1350F(½hr)AC	150	141	45	7.5	20	14.4
"	"	"	149	140	45	7.5	20	14.1
"	"	" +950F(8hrs)AC	164	152	25	5.0	11	14.6
"	"	" "	165	154	15	5.0	9	15.0
T-3944	Ti-17V-8Cr-3Al-5Co	1350F(½hr)AC	165	158	45	15.0	23	15.2
"	"	"	167	160	45	17.5	26	14.9
"	"	" +950F(8hrs)AC	169	160	5	5.0	6	15.5
"	"	" "	168	158	25	10.0	16	14.8
T-3945	Ti-17V-10Cr-3Al-0.1Be	1350F(½hr)AC	---	---	---	---	---	15.0
"	"	"	150	142	35	15.0	21	15.4
"	"	" +950F(8hrs)AC	153	140	20	10.0	12	15.6
"	"	" "	153	142	25	15.0	17	16.1
T-3946	Ti-17V-10Cr-3Al-0.2Be	1350F(½hr)AC	153	144	30	15.0	22	16.7
"	"	"	152	145	35	15.0	23	15.9
"	"	" +950F(8hrs)AC	153	144	15	7.5	12	16.2
"	"	" "	155	144	10	5.0	9	17.2
T-3947	Ti-17V-10Cr-3Al-0.3Be	1350F(½hr)AC	158	145	35	12.5	20	15.2
"	"	"	156	144	35	15.0	19	14.9
"	"	" +950F(8hrs)AC	156	141	15	10.0	11	15.5
"	"	" "	150	141	0	2.5	4	14.8

TABLE XL

TENSILE PROPERTIES OF Ti-8Mo-8V-xFe-X GROUP OF STABLE BETA ALLOY CANDIDATES

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. %	Elastic Modulus ($Ex10^{-6}$ psi)
T-3813	Ti-8Mo-8V-7.5Fe-3Al	1350F(½hr)AC	160	159	25	0	10	15.8 (1)
"	"	"	162	159	40	10.0	20	15.6 (1)
"	"	" +950F(8hrs)AC	162	160	30	2.5	12	16.2
"	"	" "	162	157	35	17.5	22	15.1
T-3814	Ti-8Mo-8V-7.5Fe-3Al-1Cu	1350F(½hr)AC	164	162	40	20.0	23	15.8
"	"	"	162	160	35	0	9	15.4
"	"	" +950F(8hrs)AC	163	159	15	2.5	6	15.7
T-3820	Ti-8Mo-8V-7.5Fe-3Al-1Co	1350F(½hr)AC	162	161	30	0	8	18.0
"	"	"	Broke on loading at 170-pounds					
"	"	" +950F(8hrs)AC	169	165	10	2.5	4	16.1
"	"	" "	170	167	35	7.5	19	16.1
T-3932	Ti-8Mo-8V-5Fe-3Al-3Cu	1350F(½hr)AC	150	147	40	2.5	11	14.9
"	"	"	150	147	45	0	14	14.1
"	"	" +950F(8hrs)AC	156	149	20	2.5	8	15.2
"	"	" "	156	149	30	2.5	9	14.8
T-3933	Ti-8Mo-8V-4Fe-3Al-5Cu	1350F(½hr)AC	154	151	45	0	14	13.8
"	"	"	156	153	45	5.0	18	14.4
"	"	" +950F(8hrs)AC	170	163	15	12.5	13	15.1
"	"	" "	84.4	---	0	0	0	14.2
T-4186	Ti-6Mo-8V-7.5Fe-3Al-3Cu	1350F(½hr)AC	167	161	45	10.0	18	15.3
"	"	"	166	163	20	10.0	14	15.1
"	"	" +950F(8hrs)AC	167	162	40	5.0	17	16.1
T-3936	Ti-8Mo-8V-5Fe-3Al-3Co	1350F(½hr)AC	166	161	45	20.0	26	15.1
"	"	"	166	162	20	20.0	18	15.6
"	"	" +950F(8hrs)AC	171	165	20	12.5	15	15.[illegible]
"	"	" "	170	163	25	17.5	19	16.0

(1) Broke outside gage length.

TABLE XLI

TENSILE PROPERTIES OF Ti-15Mo-3Al-X GROUP OF ALLOYS

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. %	Elastic Modulus ($Ex10^{-6}$psi)
T-3874	Ti-15Mo-5Fe-3Al	1350F(½hr)AC	146	145	15	2.5	6	15.3
"	"	"	145	141	35	2.5	13	15.4
"	"	" +950F(8hrs)AC	151	144	35	12.5	20	14.9
"	"	" "	151	144	35	15.0	19	15.5
T-3875	Ti-15Mo-5Fe-3Al-1Cu	1350F(½hr)AC	153	150	45	12.5	23	15.3
"	"	"	153	150	40	22.5	26	15.5
"	"	" +950F(8hrs)AC	155	150	35	15.0	20	15.6
"	"	" "	150	149	5	0	1	15.9
T-3878	Ti-15Mo-5Fe-3Al-1Ni	1350F(½hr)AC	154	152	40	5.0	17	15.5(1)
"	"	"	154	152	40	5.0	16	15.6(1)
"	"	" +950F(8hrs)AC	158	153	35	7.5	16	15.7
"	"	" "	No sample, insufficient sheet					
T-3881	Ti-15Mo-5Fe-3Al-1Co	1350F(½hr)AC	155	151	35	10.0	17	15.6
"	"	"	157	154	35	15.0	21	16.1
"	"	" +950F(8hrs)AC	158	153	25	20.0	21	15.3
"	"	" "	159	154	25	17.5	21	16.1
T-3951	Ti-15Mo-3Fe-3Al-3Cu	1350F(½hr)AC	147	144	45	10.0	19	15.2
"	"	"	Insufficient material					
"	"	" +950F(8hrs)AC	160	150	30	12.5	17	15.1
"	"	" "	158	153	15	0	5	15.7
T-3952	Ti-15Mo-2Fe-3Al-5Cu	1350F(½hr)AC	150	145	30	0	7	14.3(1)
"	"	"	151	147	35	12.5	19	14.2(1)
"	"	" +950F(8hrs)AC	171	162	10	0	4	14.4
"	"	" "	174	174	0	0	0	14.9
T-4182	Ti-13Mo-5Fe-3Al-3Cu	1350F(15min)AC	160	157	20	12.5	15	15.3
"	"	" +900F(8hrs)AC	151	---	5	---	---	15.3
"	"	" "	165	161	15	7.5	9	14.6
T-4184	Ti-11Mo-5Fe-3Al-3Cu	1350F(15min)AC	160	156	30	7.5	12	14.8
"	"	" +900F(8hrs)AC	205	195	10	---	2	15.7

(1) Broke outside gage length.

TABLE XLII

ROOM TEMPERATURE BEND RADII OF STABLE BETA SHEET ALLOY CANDIDATES

Ingot No.	Alloy	Heat Treatment: Annealed 1350F(½hr)AC	Heat Treatment: Aged 1350F(½hr)AC+ 950F(8hrs)AC
T 3732	Ti-17V-10Cr-3Al 1Co	0.80, 1.0T	1.4, 1.7T
T-3927	Ti 17V-8Cr-3Al-3Co	0.87, 0.91T	1.5T
T-3926	Ti 17V-8Cr-3Al-3Ni	0.91, 1.1T	2.1T
T-3925	Ti-17V-8Cr-3Al-3Cu	0.65T	1.5, 2.0T
T-3942	Ti 17V 8Cr-3Al-5Cu	1.1T	3.4T
T-3945	Ti-17V-10Cr 3Al-0.1Be	0.89T	1.9, 2.7T
T-3932	Ti-8Mo-8V 5Fe 3Al-3Cu	0.73T	1.4T
T-3933	Ti-8Mo-8V-4Fe-3Al-5Cu	0.98T	3.0T
T-3936	Ti 8Mo-8V-5Fe-3Al-3Co	0.95T	>9.4T
T-3874	Ti-15Mo-5Fe-3Al	0.98T	1.3T
T 3875	Ti-15Mo-5Fe-3Al-1Cu	0.83T	1.8T

TABLE XLIII

TENSILE PROPERTIES OF STABLE-BETA SHEET ALLOYS(1)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Total Elong. % in 1"	Elastic Modulus ($Ex10^{-6}$psi)
T-4669	Ti-8Mo-8V-6Fe-3Al	1450F(½hr)AC	150	147	45	2.5	16	15.6
"	"	"	149	148	50	0	12	15.6
"	"	" +900F(8hrs)AC	151	148	40	2.5	13	15.6
"	"	" "	151	149	30	0	10	16.5
T-4840	Ti-8Mo-8V-7Fe-3Al	1450F(½hr)AC	154	153	45	7.5	16	15.6
"	"	"	158	157	45	22.5	25	14.8
"	"	" +900F(8hrs)AC	155	155	45	15.0	24	17.9
"	"	" "	155	155	45	2.5	13	16.5
T-4673	Ti-17V-11Mn-3Al	1450F(½hr)AC	150	146	35	17.5	24	14.6
"	"	"	149	148	50	5.0	17	14.4
"	"	" +900F(8hrs)AC	150	149	50	12.5	24	14.9
"	"	" "	151	149	45	15.0	24	16.4
T-4676	Ti-17V-12Mn-3Al	1450F(½hr)AC	157	156	45	7.5	20	15.4
"	"	"	158	158	50	7.5	20	16.1
"	"	" +900F(8hrs)AC	155	153	40	5.0	16	15.1
"	"	" "	156	154	25	0	10(2)	15.1

(1) 0.050-inch gage sheet prepared from ½-pound ingots.
(2) Sample broke on gage mark - approximate figure only.

TABLE XLIV

BEND RADII OF STABLE-BETA SHEET ALLOYS(1)

Ingot No.	Alloy	Rolling Direction	Heat Treatment: 1450F(½hr)AC	Heat Treatment: 1450F(½hr)AC+ 900F(8hrs)AC
T-4837	Ti-8Mo-8V-6Fe-3Al	L	0.77T	1.0T
"	"	T	0.75T	1.3T
T-4840	Ti-8Mo-8V-7Fe-3Al	L	0.75T	1.0T
"	"	T	1.0 T	1.3T
T-4843	Ti-17V 11Mn 3Al	L	0.97T	1.5T
"	"	T	0.94T	1.7T
T-4846	Ti-17V-12Mn-3Al	L	1.0(2)	3.0T
"	"	T	- - -(2)	4.7T

(1) 0.050 inch gage sheet prepared from ½-pound ingots.
(2) Poor Sheet Surface.
Note: 0.015-inch pickled off sheet surface.

TABLE XLV

LAMINATED CHARPY V IMPACT STRENGTH OF STABLE-BETA SHEET ALLOYS(1)

Ingot No.	Alloy	Heat Treatment	Test Temp. °F	Actual Impact (Ft-Lbs)	Laminate Cross Section(2) Inches	Charpy Equivalent Impact(ft-lbs)
T-4838	Ti-8Mo-8V-6Fe-3Al	1450F(½hr)AC	-80	8.0	0.390 x 0.363	8.7
"	"	"	60	16.5	0.394 x 0.364	17.9
"	"	"	300	28.75	0.390 x 0.363	31.0
T-5015	"	1450F(½hr)AC+900F(8hrs)AC	-80	3.25	0.318 x 0.420	3.75
"	"	" "	60	7.75	0.317 x 0.417	9.1
"	"	" "	300	17.75	0.314 x 0.438	19.5
T-4841	Ti-8Mo-8V-7Fe-3Al	1450F(½hr)AC	-80	2.25	0.393 x 0.360	2.4
"	"	"	60	12.0	0.394 x 0.368	12.75
"	"	"	300	32.75	0.394 x 0.366	35.25
T-5016	"	1450F(½hr)AC+900F(8hrs)AC	-80	3.25	0.315 x 0.417	3.85
"	"	" "	60	9.75	0.314 x 0.443	10.1
"	"	" "	300	18.25	0.318 x 0.447	19.9
T-4844	Ti-17V-11Mn-3Al	1450F(½hr)AC	-80	2.0	0.392 x 0.352	2.25
"	"	"	60	13.0	0.394 x 0.348	14.75
"	"	"	300	25.25	0.394 x 0.351	28.0
T-5017	"	1450F(½hr)AC+900F(8hrs)AC	-80	2.25	0.317 x 0.453	2.35
"	"	" "	60	7.25	0.318 x 0.451	7.85
"	"	" "	300	19.0	0.313 x 0.455	20.7
T-4847	Ti-17V-12Mn-3Al	1450F(½hr)AC	-80	1.50	0.395 x 0.357	1.70
"	"	"	60	6.50	0.394 x 0.360	7.10
"	"	"	300	25.5	0.393 x 0.354	28.25
T-5018	"	1450F(½hr)AC+900F(8hrs)AC	-80	1.50	0.314 x 0.440	1.67
"	"	" "	60	3.25	0.317 x 0.471	3.35
"	"	" "	300	19.0	0.316 x 0.478	19.5

(1) 0.050-inch gage sheet prepared from ½-pound ingots.
(2) Standard Charpy V impact specimen cross section is 0.394-inch square.

TABLE XLVI

HOT ROLLING PRESSURE TESTS ON STABLE-BETA ALLOYS

Ingot No.	Alloy	Pass No.[1]	Total Roll Separating Force, psi	Finishing Temp. oF	Final Gage (inches)
Initial Rolling Temperature 2100F					
	Ti-13V-11Cr-3Al	1	220,000		
	"	2	270,000		
	"	3	360,000		
	"	4	370,000		
	"	5	440,000		
	"	6	510,000	1705	0.144
V-2706	Ti-17V-10Mn-3Al	1	235,000		
"	"	2	260,000		
"	"	3	320,000		
"	"	4	325,000		
"	"	5	420,000		
"	"	6	480,000	1595	0.142
V-2707	Ti-8Mo-8V-6Fe-3Al	1	230,000		
"	"	2	265,000		
"	"	3	330,000		
"	"	4	330,000		
"	"	5	430,000		
		6	490,000	1680	0.142
Initial Rolling Temperature 2250F					
	Ti-13V-11Cr-3Al	1	190,000		
	"	2	230,000		
	"	3	310,000		
	"	4	320,000		
	"	5	410,000		
	"	6	480,000	1690	0.141
V-2706	Ti-17V-10Mn-3Al	1	180,000		
"	"	2	200,000		
"	"	3	235,000		
"	"	4	260,000		
"	"	5	350,000		
"	"	6	430,000	1800	0.138
V-2707	Ti-8Mo-8V-6Fe-3Al	1	155,000		
"	"	2	185,000		
"	"	3	240,000		
"	"	4	250,000		
"	"	5	340,000		
		6	430,000	1800	0.132

(1) Mill Openings:

Pass No.	1	2	3	4	5	6
Opening, inches	0.6	0.45	0.3	0.2	0.1	0.04

TABLE XLVII

COLD ROLLING PRESSURE TESTS ON STABLE-BETA ALLOYS

Ingot No.	Alloy	Mill Opening Inches	Pass No.	Entering Mill	Leaving Mill	% Reduction	Total Roll Separating Force PSI
-------	Ti-13V-11Cr-3Al	0.119	1	0.132	0.130	1.14	190,000
	"	0.109	2	0.130	0.129	0.54	280,000
	"	0.099	3	0.129	0.126	2.23	350,000
V-2706	Ti-17V-10Mn-3Al	0.115	1	0.128	0.127	0.78	205,000
"	"	0.105	2	0.127	0.126	0.47	290,000
"	"	0.095	3	0.125	0.123	1.6	370,000
V-2707	Ti-8Mo-8V-6Fe-3Al	0.121	1	0.135	0.134	0.74	215,000
"	"	0.111	2	0.134	0.133	0.6	310,000
"	"	0.101	3	0.132	0.130	1.6	380,000

TABLE XLVIII

ROOM TEMPERATURE AND 600F NOTCH TENSILE PROPERTIES OF STABLE BETA SHEET ALLOYS(1)
(All Heat Treated 1450F(½hr)AC)

Ingot No	Alloy	Test Temp. °F	Notch Tensile Strength Kpsi		Ratio Notched UTS/ Unnotched UTS
V 2706	Ti 17V 10Mn 3Al	60	177)		
"	"	60	179)		
"	"	60	180)	178.6	1.18
"	"	60	178)	Average	
"	"	60	179)		
V 2707	Ti 8Mo 8V 6Fe 3Al	60	162)		
"	"	60	168)		
"	"	60	175)	171.4	1.15
"	"	60	177)	Average	
"	"	60	175)		
V 2706	Ti 17V 10Mn 3Al	600	146)		
"	"	600	141)	143.6	1.07
"	"	600	144)	Average	
V 2707	Ti 8Mo 8V 6Fe 3Al	600	139)		
"	"	600	141)	139.3	1.15
"	"	600	138)	Average	

(1) 0.050 inch gage sheet prepared from 30 pound ingots.

TABLE XLIX

600F TENSILE PROPERTIES OF STABLE-BETA SHEET ALLOYS(1)
(Heat Treatment 1450F(½hr)AC)

Ingot No.	Alloy	UTS Kpsi	YS Kpsi	Elongation, % Local	Elongation, % Uniform	Elongation, % in 1"	Modulus ($Ex10^{-6}$psi)
V-2706	Ti-17V-10Mn-3Al	119	107	35	7.5	14	11.1
"	"	123	111	45	7.5	18	11.8
"	"	125	116	50	5.0	18	14.6
V-2707	Ti-8Mo-8V-6Fe-3Al	122	112	35	2.5	9	12.9(2)
"	"	117	106	15	0	4	13.4(2)
"	"	125	113	45	15.0	23	12.8

(1) 0.050-inch gage sheet prepared from 30-pound ingots.
(2) Samples had poor sheet surface.

TABLE L

CREEP STABILITY DATA FOR STABLE-BETA ALLOYS(1)
(Heat Treatment 1450F(½hr)AC)

Ingot No.	Alloy	Temp °F	Stress Kpsi	Time Hours	% Def.	Subsequent Tensile Properties: UTS Kpsi	YS Kpsi	Elongation, % Local	Elongation, % Uniform	Elongation, % in 1"	Modulus ($Ex10^{-6}$psi)
V-2706	Ti-17V-10Mn-3Al	---	---	---	-----	151	145	35	7.5	19	15.7
"	"	600	100	150	0.220	161	157	30	5.0	12	15.9
"	"	600	100	150	0.220	161	158	30	5.0	12	15.9
"	"	600	100	150	0.196	159	158	30	0	8	15.9
V-2707	Ti-8Mo-8V-6Fe-3Al	---	---	---	-----	149	147	45	2.5	16	15.6
"	"	600	99	150	0.204	148	147	10	2.5	3	14.7
"	"	600	99	150	0.180	151	151	20	7.5	10	14.7
"	"	600	99	150	0.192	150	150	15	2.5	6	15.5

(1) 0.050-inch gage sheet prepared from 30-pound ingots.

TABLE LI

OXIDATION BEHAVIOR(1) OF STABLE BETA SHEET ALLOYS

Ingot No.	Alloy	Test No.	Weight Sample (Gms)	Weight Unexposed Sample + Crucible (Gms)	Weight Exposed Sample + Crucible (Gms)	Weight Gain (Gms)	Weight Gain Gms/Sq.Cm. of Surface Area (Average)
V-2706	Ti-17V-10Mn-3Al	1	3.5202	35.0131	35.1492	0.1361	
"	"	2	3.7570	31.4322	31.5783	0.1461	0.0104
"	"	3	3.4833	31.3570	31.4775	0.1205	
V-2707	Ti-8Mo-8V-6Fe-3Al	1	3.9677	35.4643	35.6948	0.2305	
"	"	2	3.7041	31.3860	31.6628	0.2768	0.0182
"	"	3	4.1805	32.0025	32.1990	0.1965	

(1) All samples were exposed in open crucibles for 2 hours at 1500F.
(2) 0.050-inch gage sheet.

TABLE LII

STRESS CORROSION RESISTANCE[1] OF Ti-8Mo-8V-6Fe-3Al AND Ti-17V-10Mn-3Al SHEET ALLOYS

Ingot No.	Alloy	Heat Treatment	Bend Radius of Samples	Reverse Bend Results and Visual Examination (9x)	Metallographic Examination (250x)
V-2706	Ti-17V-10Mn-3Al	1450F-½hr-AC	1.2T	Unexposed control sample broke on reverse bend. Stress corrosion cracks visible. All exposed samples broke on reverse bend.	Cracks visible
V-2707	Ti-8Mo-8V-6Fe-3Al	1450F-½hr-AC	1.2T	Unexposed control sample broke on reverse bend. Some stress corrosion cracks visible. All exposed samples broke on reverse bend.	Cracks visible.

(1) All samples bent to radius indicated and exposed for 2 hours at 800F with salt coating.
(2) 0.050-inch gage sheet prepared from 30-pound ingots.

TABLE LIII

TENSILE PROPERTIES OF WELDED STABLE BETA SHEET ALLOYS

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS(1) Kpsi	Total Elongation in 0.2"	Total Elongation in 0.5"	Modulus (Ex10-6psi)
V-2706	Ti-17V-10Mn-3Al	1450F(½hr)AC+Weld	85	---	0	0	13.6
"	"	"	46	---	0	0	13.0
"	"	"	87	---	0	0	14.0
"	"	"	61	---	0	0	12.7
"	"	"	113	---	0	0	14.5
V-2707	Ti-8Mo-8V-6Fe-3Al	1450F(½hr)AC+Weld	70	---	5	2	14.5
"	"	"	133	---	0	0	14.0
"	"	"	78	---	0	0	13.1
"	"	"	54	---	0	0	13.6
"	"	"	99	---	0	0	16.5
"	"	"	137	---	0	0	14.7

(1) All weld specimens broke before reaching yield stress.

TABLE LIV

BEND TESTS OF WELDED STABLE BETA ALLOYS AND WELD STABILITY TESTS

Ingot No	Alloy	Processing	Minimum Bend Radius
(a) Bend Tests			
(1) Control (Unwelded) Samples			
V 2706	Ti 17V 10Mn 3A1	1450F(½hr)AC	1.2T
V 2707	Ti-8Mo 8V 6Fe-3A1	"	1.2T
(2) Welded samples			
V 2706	Ti-17V 10Mn 3A1	1450F(½hr)AC+Weld	Broke at 12T
V 2707	Ti 8Mo 8V 6Fe 3A1	"	"
(b) Weld Stability Tests			
V 2706	Ti 17V 10Mn 3A1	1450F(½hr)AC+Weld, exposed at 650F for 500 hrs.	>13T
V 2707	Ti 8Mo 8V-6Fe 3A1	" "	>13T

TABLE LV

TENSILE PROPERTIES OF THREE ALLOYS CONTAINING COBALT(1)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Elongation, % Local	Uniform	Total(2)	Modulus ($Ex10^{-6}psi$)
T-5495	Ti-8Mo-8V-5Co-3Al	1350F(15min)AC	145	144	45	12.5	24	13.4
"	"	1350F(15min)AC	144	142	45	12.5	22	13.7
"	"	1350F(15min)AC+900F(8hrs)AC	172	161	30	7.5	14	14.2
"	"	1350F(15min)AC+900F(8hrs)AC	176	165	25	2.5	10	15.0
"	"	1450F(15min)WQ	144	140	45	12.5	23	13.5
"	"	1450F(15min)WQ+900F(8hrs)AC	162	152	35	12.5	17	14.0
"	"	1450F(15min)WQ+900F(8hrs)AC	163	154	30	2.5	14	14.0
"	"	1450F(15min)WQ+900F(16hrs)AC	193	178	15	7.5	11	15.2
"	"	1450F(15min)WQ+900F(16hrs)AC	194	179	5	5.0	8	15.5
"	"	1500F(10min)WQ	143	139	45	12.5	23	12.6
"	"	1500F(10min)WQ+900F(8hrs)AC	203	188	10	5.0	6	15.1
"	"	1500F(10min)WQ+900F(8hrs)AC	203	188	15	2.5	8	15.1
"	"	1500F(10min)WQ+900F(16hrs)AC	219	204	15	5.0	9	15.8
"	"	1500F(10min)WQ+900F(16hrs)AC	216	202	15	5.0	9	15.7
T-5494	Ti-17V-7.5Co-3Al	1350F(15min)AC	155	150	45	15.0	25	13.9
"	"	1350F(15min)AC	156	151	40	7.5	17	13.9
"	"	1350F(15min)AC+900F(8hrs)AC	194	176	10	5.0	11	14.7
"	"	1350F(15min)AC+900F(8hrs)AC	194	177	10	7.5	8	15.0
T-5463	Ti-8Mo-8V-4Fe-3Al-4Co	1350F(15min)AC	161	159	45	17.5	24	13.8
"	"	1350F(15min)AC	160	159	45	10.0	19	13.8
"	"	1350F(15min)AC+900F(8hrs)AC	159	158	15	7.5	9	14.0
"	"	1350F(15min)AC+900F(8hrs)AC	161	161	45	15.0	22	14.2

(1) 0.050-inch gage sheet prepared from ½-pound ingots.
(2) In 1-inch.

TABLE LVI

EFFECT OF AGING AT 1100F ON THE MECHANICAL PROPERTIES OF Ti-17V-7.5Co-3Al SHEET ALLOY[1]

Ingot No.	Solution Treatment	Vickers Hardness After Aging at 1100F: 0	5 min	10 min	25 min	30 min	1 hr	2 hrs	4 hrs	8 hrs	16 hrs
Hardness Response											
T-5494	1350F(15min)AC	331	333	331	335	333	339	343	346	343	344

Button No.	Heat Treatment	UTS Kpsi	YS Kpsi	El. Local	El. Uniform	% El. in 1"	Modulus ($Ex10^{-6}$psi)
Tensile Results							
T-6120	1350F(15min)AC	152	147	45	5.0	14	13.9
"	1350F(15min)AC	151	147	45	5.0	17	13.4
"	1350F(15min)AC+1100F(10min)AC	152	146	45	15.0	23	13.5
"	1350F(15min)AC+1100F(10min)AC	154	147	40	12.5	21	13.8
"	1350F(15min)AC+1100F(30min)AC	153	146	45	10.0	21	13.3
"	1350F(15min)AC+1100F(30min)AC	154	147	40	10.0	18	13.7
"	1350F(15min)AC+1100F(16hrs)AC	169	154	25	10.0	16	14.2
"	1350F(15min)AC+1100F(16hrs)AC	170	156	15	7.5	13	14.5

(1) 0.050-inch gage sheet produced from ½-pound ingots.

TABLE LVII

BEND RADII OF "STABILIZED" METASTABLE BETA SHEET ALLOYS(1)

Ingot No.	Alloy	Solution Treatment	Bend Radius After Aging 0	950F 8hrs	1000F 8hrs	1100F 8hrs	1250F 8hrs
V 2989	Ti 8Mo 8V 2Fe-3Al	1500F 10mins AC	1.4T	4.2T	3.6T	2.7T	2.3T
V 2966	Ti 8Mo 8V 5Co 3Al	"	1.4T	3.9T	3.7T	2.8T	2.5T
V-2967	Ti 17V 7.5Co 3Al	"	1.5T	5.2T	3.8T	3.7T(2)	2.4T
V-2858	Ti 17V 2Fe 2Co 3Al	"	2.1T	4.8T	4.3T	3.0T	2.6T

(1) 0.050-inch gage sheet prepared from 30-pound ingots.
(2) Anomalous figure caused by poor sheet surface.

TABLE LVIII

ROOM TEMPERATURE AND 600F TENSILE PROPERTIES OF "STABILIZED" METASTABLE BETA SHEET ALLOYS

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	% in 2" Local Elong.	% in 2" Uniform Elong.	% in 2" Total Elong.	Modulus (Ex10-6psi)
(a) Room Temperature								
V-2989	Ti-8Mo-8V-2Fe-3Al	1500F-10mins-AC+1100F-8hrs-AC	151	140	40	8.75	13.5	14.9
"	"	"	151	[illegible]	45	10	15	15.2
"	"	"	142	134	45	5	14	14.2
"	"	"	151	140	45	11.25	17	14.5
"	"	"	[illegible]	139	45	5	11	14.5
		Average	149	139	45	8	14	14.7
V-2900	Ti-8Mo-8V-5Co-3Al	1500F-10mins-AC+1100F-8hrs-AC	[illegible]	173	10	5	7.5	15.4(1)
"	"	"	175	[illegible]	20	1.25	6	15.1
"	"	"	174	169	10	2.5	6	15.0(1)
"	"	"	174	165	25	8.75	11	15.1
"	"	"	176	[illegible]	30	8.75	12.5	15.2
		Average	176	168	20	5.25	8.5	15.2
V-2967	Ti-17V-7.5Co-3Al	1500F-10mins-AC+1100F-8hrs-AC	165	141	15	7.5	8.5	16.4(2)
"	"	"	167	145	15	10	11	17.0(2)
"	"	"	168	155	20	8.75	10	15.7
"	"	"	168	157	5	5	7	14.9
"	"	"	166	154	21	5	6.5	14.9
		Average	167	150	15	7.5	8.5	15.8
V-2858	Ti-17V-2Fe-2Co-3Al	1500F-10mins-AC+1100F-8hrs-AC	153	138	45	11.25	16.5	14.2
"	"	"	149	138	35	7.5	11	13.8
"	"	"	151	139	35	6.25	13.5	14.0
"	"	"	154	140	35	8.75	15	13.9
"	"	"	146	134	45	8.75	14.5	13.8
		Average	151	138	40	8.5	14	13.9

(1) Sample broke outside gage length
(2) Sample broke in head - test finished in file grips.

TABLE LVIII (Continued)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	% in 2" Local Elong.	% in 2" Uniform Elong.	% in 2" Total Elong.	Modulus ($Ex10^{-6}$psi)
(b) 600F								
V-2989	Ti-8Mo-8V-2Fe-3Al	1500F-10min-AC+1100F-8hrs-AC	126	105	35	7.5	10	14.7
"	"	"	126	106	35	8.75	11.5	13.9
"	"	"	123	101	35	6.25	10.5	13.6
"	"	"	112	105	25	0	3.5	13.6(3)
"	"	"	123	105	35	3.75	8.5	14.9
		Average	122	104	35	5.25	9	14.1
V-2900	Ti-8Mo-8V-5Co-3Al	1500F-10mins-AC+1100F-8hrs-AC	153	134	30	6.25	11	14.2
"	"	"	---	---	---	---	---	14.0
"	"	"	148	128	35	3.75	9.5	15.1
"	"	"	152	133	15	5.0	7	14.1
"	"	"	152	132	35	3.75	9.5	13.3
		Average	151	132	30	4.5	9	14.1
V-2967	Ti-17V-7.5Co-3Al	1500F-10mins-AC+1100F-8hrs-AC	148	127	45	13.75	16.5	12.6
"	"	"	149	128	45	7.5	14.0	13.4
"	"	"	150	129	45	15	18	13.8
"	"	"	151	136	45	8.75	13.5	13.5
"	"	"	150	129	35	8.75	16	13.8
		Average	150	130	42.5	10.75	15.5	13.4
V-2858	Ti-17V-2Fe-2Co-3Al	1500F-10mins-AC+1100F-8hrs-AC	127	108	35	5	10.5	14.3
"	"	"	124	103	35	6.25	11.5	13.9
"	"	"	130	108	35	7.5	13	13.0
"	"	"	126	107	15	5	7	12.4
"	"	"	127	107	35	5	11	---
		Average	127	107	30	6	10.5	13.4

(3) Flaw in sheet
(4) 0.050 inch gage sheet prepared from 50-pound ingots.
Note: Percentages of room temperature yield strength retained at 600F were:
Ti-8Mo-8V-2Fe-3Al - 75%
Ti-8Mo-8V-5Co-3Al - 78%
Ti-17V-7.5Co-3Al - 86%
Ti-17V-2Fe-2Co-3Al - 7%

TABLE LIX

ROOM TEMPERATURE AND 600F NOTCH TENSILE PROPERTIES OF "STABILIZED" METASTABLE BETA SHEET ALLOYS(1)(2)

Ingot No.	Alloy	Heat Treatment	Test Temp °F	NTS Kpsi	Average	Ratio NTS/UTS
V2989	Ti-8Mo-8V 2Fe 3Al	1500F 10mins AC+1100F 8hrs AC	RT	175		
"	"	"	"	173		
"	"	"	"	172	174	1.16
"	"	"	"	173		
"	"	"	"	177		
"	"	"	600F	134		
"	"	"	"	137		
"	"	"	"	136	136	1.11
"	"	"	"	138		
"	"	"	"	134		
V 2900	Ti 8Mo 8V 5Co 3Al	1500F 10mins AC+1100F 8hrs AC	RT	108		
"	"	"	"	109		
"	"	"	"	139	117	0.66
"	"	"	"	121		
"	"	"	"	110		
"	"	"	600F	154		
"	"	"	"	160		
"	"	"	"	160	158	1.04
"	"	"	"	157		
"	"	"	"	160		
V 2967	Ti 17V 7,5Co 3Al	1500F 10mins-AC+1100F 8hrs-AC	RT	128		
"	"	"	"	116		
"	"	"	"	136	131	0.78
"	"	"	"	134		
"	"	"	"	139		
"	"	"	600F	161		
"	"	"	"	154		
"	"	"	"	156	157	1.04

TABLE LIX (Continued)

Ingot No.	Alloy	Heat Treatment	Test Temp °F	NTS Kpsi	Average	Ratio NTS/UTS
V-2967	Ti 17V-7.5Co 3Al	1500F 10mins AC+1100F 8hrs-AC	600F	155		
"	"	"	"	157		
V-2971	Ti-17V 2Fe 2Co-3Al	1500F-10mins AC+1100F 8hrs AC	RT	161		
"	"	"	"	160		
"	"	"	"	160	162	[illegible]
"	"	"	"	158		
"	"	"	"	170		
"	"	"	600F	139		
"	"	"	"	144		
"	"	"	"	140	140	[illegible]
"	"	"	"	137		
"	"	"	"	139		

(1) $K_t = 8$
(2) 0.050-inch gage sheet

TABLE LX

CREEP STABILITY OF "STABILIZED" METASTABLE BETA SHEET ALLOYS(1)

Ingot No.	Alloy	Heat Treatment	Creep Exposure Temp °F	Creep Exposure Stress Kpsi	Creep Exposure Time Hrs	% Def.	Subsequent Tensile Properties UTS Kpsi	YS Kpsi	% in 1" Local Elong.	% in 1" Uniform Elong.	% in 1" Total Elong.	Modulus (Ex10^{-6}psi)
V2989	Ti-8Mo-8V-2Fe-3Al	1500F-10mins-AC+1100F-8hrs-AC	600	93.5	150	0.098	152	143	35	12.5	18	14.6
"	"	"	"	"	"	0.141	150	140	35	10	18	14.6
"	"	"	"	"	"	0.116	151	142	35	10	16	14.9
"	"	"	"	"	500	0.160	157	142	30	10	16	15.0
"	"	"	"	"	"	0.193	156	147	30	10	17	15.1
"	"	"	"	"	"	0.244	156	143	35	7.5	14	15.0
V2900	Ti-8Mo-8V-5Co-3Al	"	600	119	150	0.221	165	163	5	2.5	4	15.0
"	"	"	"	"	"	0.178	171	168	5	0	3	15.0
"	"	"	"	"	"	0.170	170	167	5	0	1	15.1
"	"	"	"	"	500	0.098	166	162	---	---	---	16.8(2)
"	"	"	"	"	"	0.215	167	164	5	0	2	14.5
"	"	"	"	"	"	0.207	167	167	5	2.5	4	15.4
V2967	Ti-17V-7.5Co-3Al	"	600	117	150	0.174	164	159	10	2.5	6	14.7
"	"	"	"	"	"	0.192	161	158	5	2.5	6	14.2
"	"	"	"	"	"	0.130	165	157	5	2.5	7	14.6
"	"	"	"	"	500	0.513	172	171	---	---	---	14.9(2)
"	"	"	"	"	"	0.349	167	163	5	2.5	3	14.6
"	"	"	"	"	"	0.291	169	162	5	2.5	3	14.6
V2971	Ti-17V-2Fe-2Co-3Al	"	600	96	150	0.145	151	138	30	7.5	13	13.8
"	"	"	"	"	"	0.152	154	142	30	7.5	14	14.2
"	"	"	"	"	"	0.141	150	139	30	7.5	14	14.1
"	"	"	"	"	500	0.622	173	171	15	0	4	14.8
"	"	"	"	"	"	0.655	181	172	5	0	3	14.9
"	"	"	"	"	"	0.553	174	166	5	0	4	15.0

(1) 0.050-inch gage sheet prepared from 30-pound ingots.
(2) Sample broke outside gage length.

TABLE LXI

AGING RESPONSE OF METASTABLE BETA SHEET ALLOYS(1)

Button No.	Alloy	Solution Treatment	Aging Time Hours	Hardness Response at Aging Temperature, °F: 0	800	850	900	950
T-5056	Ti-17V-1.5Fe 3Al	1500F-10min WQ	0	266				
"	"	"	1		282	331	376	369
"	"	"	2		365	401	440	368
"	"	"	4		424	410	393	375
"	"	"	8		437	417	390	339
"	"	"	16		428	428	379	356
"	"	"	24		429	428	402	366
T-5057	Ti-17V-4Fe-3Al	1500F-10min WQ	0	289				
"	"	"	1		288	285	284	283
"	"	"	2		288	285	300	305
"	"	"	4		301	303	344	358
"	"	"	8		327	335	393	361
"	"	"	16		391	420	399	366
"	"	"	24		424	433	412	371
T-5058	Ti-8Mo-8V 1Fe-3Al	1500F-15min-WQ	0	279				
"	"	"	1		280	279	290	324
"	"	"	2		306	323	373	378
"	"	"	4		377	405	397	393
"	"	"	8		426	441	413	371
"	"	"	16		448	454	419	381
"	"	"	24		443	448	428	396
T-5059	Ti-8Mo-8V-3Fe 3Al	1500F-15min-WQ	0	293				
"	"	"	1		294	288	296	307
"	"	"	2		294	285	299	303
"	"	"	4		312	304	353	367
"	"	"	8		350	349	403	366
"	"	"	16		407	424	437	395
"	"	"	24		432	450	445	406

(1) 0.050-inch gage sheet prepared from ½ pound ingots.

TABLE LXII

TENSILE PROPERTIES OF METASTABLE BETA SHEET ALLOYS (1)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. %	Uniform Elong. %	Elong. % in 1"	Elastic Modulus ($Ex10^{-6}$psi)
T-4678	Ti-17V-1.5Fe-3Al	1500F 10min)WQ	114	107	45	10.0	15	9.77
"	"	"	114	109	45	2.5	13	9.18
"	"	" +900F(8hrs)AC	187	175	20	2.5	5	14.2
"	"	" "	198	184	20	0	6	15.4
T-4680	Ti-17V-4Fe-3Al	1500F(10min)WQ	126	119	55	20.0	26	11.4
"	"	"	127	121	55	17.5	26	11.2
"	"	" +900F(8hrs)AC	207	166	20	7.5	8	13.9
"	"	" "	201	186	15	2.5	5	15.0(2)
T-4827	Ti-8Mo-8V-[illegible]Fe-3Al	1500F(15min)WQ	124	118	50	2.5	14	9.23
"	"	"	122	114	55	7.5	19	9.63
"	"	" +900F(8hrs)AC	196	181	15	5.0	6	14.2
"	"	" "	198	181	10	2.5	4	14.5
T-4829	Ti-8Mo-8V-3Fe-3Al	1500F(15min)WQ	126	124	55	20.0	28	10.9
"	"	"	126	123	50	20.0	25	11.2
"	"	" +900F(8hrs)AC	171	157	15	2.5	6	----
"	"	" "	178	166	25	2.5	6	15.3(2)

(1) 0.050-inch gage sheet prepared from ½-pound ingots.
(2) Sample broke outside gage length.

TABLE LXIII

TENSILE PROPERTIES OF Ti-8Mo-8V-2Fe-3Al SHEET ALLOY, HEAT V-2793

Heat Treatment	UTS Kpsi	YS Kpsi	Elongation, % Local	Elongation, % Uniform	Elongation, % % in 2"	Modulus ($Ex10^{-6}$psi)
1500F(15min)WQ	123	118	65	6.25	16	10.5
"	125	120	50	7.5	17	9.8
" +800F(1hr)AC	120	115	65	10.0	21	11.2
" "	120	116	60	7.5	16	10.8
" +800F(8hrs)AC	129	122	50	6.25	15	11.5
" "	130	125	50	8.75	16	11.2
" +800F(24hrs)AC	212	193	15	2.5	4	14.4(2)
" "	210	190	15	2.5	3.5	14.4(2)
" +850F(1hr)AC	121	113	60	7.5	18	11.0
" "	120	117	65	15.0	23	10.8
" +850F(8hrs)AC	170	150	20	2.5	8	12.9
" "	175	154	25	2.5	6.5	12.9
" +850F(24hrs)AC	207	191	15	3.75	5.5	15.2
" "	206	196	10	1.25	1	15.0(1)(2)
" +900F(1hr)AC	122	119	60	15.0	23	11.4
" "	122	119	60	5.0	16	11.3
" +900F(8hrs)AC	196	179	10	1.25	2	14.9(1)(2)
" "	199	182	15	2.5	7	15.1
" +900F(16hrs)AC	197	187	25	2.5	7.5	15.1
" "	193	185	15	1.25	4.5	14.6(2)
" +900F(24hrs)AC	203	190	5	2.5	4.5	15.3(1)(2)
" "	206	192	15	2.5	6	15.7
" +900F(32hrs)AC	196	185	15	2.5	6	15.1
" "	201	195	20	2.5	4.5	14.3(2)
" +900F(64hrs)AC	198	188	15	3.75	7.5	15.1
" "	197	193	10	1.25	3.5	14.3(2)

(1) Sample broke outside gage length.
(2) Sample broke in head - test finished in file grips.

TABLE LXIII (Continued)

Heat Treatment	UTS Kpsi	YS Kpsi	Local	Uniform	% in 2"	Modulus ($Ex10^{-6}psi$)
1500F(15min)WQ+950F(1hr)AC	127	120	50	7.5	17	11.3
" "	127	122	50	10.0	17	11.5
" +950F(2hrs)AC	151	140	35	2.5	9.5	12.2
" "	148	137	30	2.5	8	12.1
" +950F(4hrs)AC	185	171	15	2.5	7	14.4
" "	187	175	15	2.5	7	14.8
" +950F(6hrs)AC	187	183	25	2.5	7	14.8
" "	189	178	25	2.5	7	14.7
" +950F(8hrs)AC	192	181	15	2.5	6.5	14.9(1)(2)
" "	191	178	25	3.75	7.5	14.9
" +950F(12hrs)AC	187	176	30	3.75	8.5	14.8
" "	188	175	25	2.5	7	15.1
" +950F(16hrs)AC	188	177	25	2.5	6.5	15.3
" "	188	178	30	2.5	6.5	15.2(2)
" +950F(20hrs)AC	188	179	20	1.25	10	15.1
" "	188	179	20	1.25	4	15.2(2)
" +950F(24hrs)AC	193	180	15	3.75	6.5	15.2
" "	196	188	20	2.5	6.5	15.0(2)
" +950F(32hrs)AC	185	174	25	2.5	6.5	15.1
" "	186	174	25	2.5	7.5	15.4(2)
" +1000F(1hr)AC	130	124	50	3.75	10	11.4
" "	135	127	40	14.4(3)	16.5	11.4
" +1000F(2hrs)AC	169	156	35	6.25	9.5	14.3
" "	166	153	30	5.0	10	13.8
" +1000F(4hrs)AC	179	166	30	5.0	9.5	14.8
" "	177	162	30	6.25	9.5	14.5
" +1000F(6hrs)AC	172	158	35	5.0	9.5	14.6
" "	168	155	35	4.0	10	14.5

(3) Sample had double neck, resulting in inability to obtain true uniform elongation result.
(4) 0.050-inch gage sheet prepared from 30-pound ingot.

TABLE LXIV

TENSILE PROPERTIES OF Ti-17V-4Fe-3Al SHEET ALLOY, HEAT V-2729 (3)

Heat Treatment		UTS Kpsi	YS Kpsi	Elongation, % Local	Elongation, % Uniform	Elongation, % % in 2"	Modulus (Ex10-6psi)
1500F(10min)WQ		125	123	55	5.0	16	12.0
"		125	122	60	7.5	18	12.2
"	+800F(1hr)AC	125	123	60	11.25	17	12.2
"	"	123	122	55	6.25	17	12.5
"	+800F(8hrs)AC	126	123	55	7.5	19	12.5
"	"	126	123	30	5.0	13	12.2
"	+800F(24hrs)AC	150	142	30	0	7	13.2
"	"	151	150	10	3.75	6	12.9
"	+800F(64hrs)AC	203	188	0	0	0	14.1 (1)
"	"	212	195	0	0	0	14.2 (1)
"	+850F(1hr)AC	122	121	60	6.25	18	12.0
"	"	125	123	60	2.5	16	12.6
"	+350F(8hrs)AC	128	125	10	2.5	7.5	12.6
"	"	129	125	45	0	8	12.6
"	+850F(24hrs)AC	203	189	10	0	3.5	15.1
"	"	---	---	---	---	---	14.3 (1)
"	+850F(64hrs)AC	195	---	---	---	---	14.3 (1)
"	"	214	201	15	1.25	4	15.3
"	+900F(1hr)AC	125	123	55	6.25	16.5	12.7
"	"	122	121	55	1.25	8.5	12.6
"	+900F(2hrs)AC	124	123	45	7.5	16.5	12.0 (1)
"	"	126	124	45	6.25	16	11.8
"	+900F(4hrs)AC	138	130	40	8.75	13	12.8
"	"	130	124	40	8.75	15	12.4
"	+900F(8hrs)AC	157	144	35	6.25	11.5	13.8
"	"	167	152	20	2.5	6.5	14.0
"	+900F(16hrs)AC	191	175	30	2.5	6.5	14.7 (2)
"	"	190	174	25	3.75	6.5	14.8

(1) Sample broke outside gage length.
(2) Sample broke in head - test finished in file grips.
(3) 0.050-inch gage sheet prepared from 30-pound ingot.

TABLE LXIV (Continued)

Heat Treatment	UTS Kpsi	YS Kpsi	Elongation, % Local	Uniform	% in 2"	Modulus ($Ex10^{-6}$psi)
1500F(10min)WQ+900F(24hrs)AC	200	184	25	6.25	9	15.6
" "	196	---	---	---	---	15.6 (1)
" +900F(32hrs)AC	197	186	30	2.5	6.5	15.0 (2)
" "	199	184	30	5.0	8.5	15.4
" +900F(64hrs)AC	195	182	20	1.25	6.0	15.3
" "	197	185	20	1.25	5.0	15.7
" +950F(1hr)AC	124	122	55	6.25	15.5	12.7
" "	125	123	50	7.5	17	12.7
" +950F(2hrs)AC	126	121	30	5.0	12.5	12.3
" "	130	125	25	5.0	12.5	12.3
" +950F(4hrs)AC	157	143	25	5.0	9	13.4
" "	156	143	20	3.75	7.5	13.4
" +950F(6hrs)AC	166	151	20	7.5	11	13.8
" "	160	146	20	7.5	10.5	13.4
" +950F(8hrs)AC	169	154	30	5.0	10.5	14.5
" "	169	154	30	5.0	10.5	14.1
" +950F(16hrs)AC	184	170	30	2.5	7.5	15.1
" "	184	169	20	5.0	9.5	14.8
" +950F(20hrs)AC	179	165	25	5.0	9.5	15.0
" "	181	167	35	8.75	13	15.3
" +950F(24hrs)AC	182	170	35	2.5	9.5	15.5
" +950F(25hrs)AC	181	168	35	6.25	10	15.2
" +950F(32hrs)AC	185	174	30	5.0	11	14.5 (2)
" "	187	173	20	6.25	9.5	15.2
" +950F(64hrs)AC	182	168	35	3.75	10.5	14.6
" "	184	172	35	3.75	8	15.3
" +1000F(1hr)AC	128	123	35	8.75	17	12.1
" "	126	122	30	16.25	18	12.0
" +1000F(2hrs)AC	135	128	40	8.75	15.5	12.4
" "	142	132	40	6.25	14	12.7
" +1000F(4hrs)AC	155	142	25	7.5	13	13.7
" "	159	145	30	7.5	13	14.1
" +1000F(6hrs)AC	160	147	30	6.25	13	13.9
" "	158	145	40	8.75	14	13.8
" +1000F(16hrs)AC	170	149	25	2.5	7	14.7
" "	174	159	45	6.25	11.5	15.4

TABLE LXV

AGE HARDENING RESPONSE FOR Ti-17V-7.5Co-3Al SHEET ALLOY(1)

Ingot No.	Alloy	Solution Treatment	Aging Time Hours	Vickers Hardness After Aging Temperature, °F				
				0	800	850	900	950
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ	0	340				
"	"	"	1		340	344	353	362
"	"	"	2		343	353	383	396
"	"	"	4		351	412	416	405
"	"	"	8		417	426	433	433
"	"	"	16		459	449	452	446
"	"	"	24		411	464	455	429

(1) 0.050-inch gage sheet prepared from 30 pound ingots.

TABLE LXVI

AGE HARDENING RESPONSE FOR Ti-8Mo-8V-5Co-3Al(1)

Ingot No.	Alloy	Solution Treatment	Aging Time Hours	Vickers Hardness After Aging Temperature, °F				
				0	800	850	900	950
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ	0	344				
"	"	"	1		346	335	329	331
"	"	"	2		334	335	330	328
"	"	"	4		337	337	336	332
"	"	"	8		343	351	353	357
"	"	"	16		374	388	391	371
"	"	"	24		373	404	401	426

(1) 0.050-inch gage sheet prepared from 30-pound ingots.

TABLE LXVII

AGING RESPONSE OF Ti-17V-2Fe-2Co-3Al SHEET ALLOY, V2858(1)

Ingot No.	Alloy	Solution Treatment	Aging Time Hours	Vickers Hardness After Aging Temperature, °F: 0	800	850	900	950
V2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ	0	294				
"	"	"	1		286	289	289	287
"	"	"	2		311	301	297	301
"	"	"	4		349	333	313	339
"	"	"	8		400	387	408	387
"	"	"	16		413	420	415	389
"	"	"	24		450	435	447	410

(1) 0.050-inch gage sheet prepared from 30-pound ingot.

TABLE LXVIII

TENSILE PROPERTIES OF Ti-8Mo-8V-5Co-3Al, INGOT NO. V-2900[(3)]

Heat Treatment	UTS Kpsi	YS Kpsi	% Elongation Local	Uniform	in 2-inches	Modulus ($E\times10^{-6}$psi)
1500F(10min)WQ	134	132	60	15.0	23	12.2
"	136	134	60	16.25	22.5	12.0
" +800F(1hr)AC	152	150	60	2.5	13.5	13.8
" "	148	147	65	2.5	17	13.2
" +800F(8hrs)AC	141	139	50	11.25	18.5	12.8
" "	139	136	50	11.25	18	12.4
" +800F(16hrs)AC	168	161	5	1.25	2	13.8(1)
" "	165	153	30	3.75	9	12.9
" +800F(24hrs)AC	187	172	20	1.25	6.5	13.8
" "	183	176	30	1.25	6	13.9
" +850F(1hr)AC	144	144	50	0	8	12.8
" "	151	151	45	3.75	11.5	13.5
" +850F(4hrs)AC	151	150	30	7.5	13.5	13.5(1)
" "	155	154	50	6.25	13.0	13.9
" +850F(16hrs)AC	184	175	20	6.25	8.5	14.0
" "	185	176	15	3.75	8	13.9
" +850F(24hrs)AC	226	218	5	0	1	15.3(2)
" "	---	---	---	---	---	14.7(2)
" +900F(1hr)AC	145	144	50	1.25	12.5	13.4
" +900F(4hrs)AC	149	148	40	11.25	19	12.9
" "	149	147	50	10.0	20	13.0
" +900F(8hrs)AC	161	160	25	1.25	9.5	13.1
" "	160	156	15	7.5	11.0	13.7
" +900F(12hrs)AC	176	166	20	5.0	7	13.7
" "	172	167	10	1.25	4	13.8
" +900F(16hrs)AC	92	180	10	1.25	3	14.7
" "	178	172	10	0	3	14.0
" +900F(24hrs)AC	216	203	10	1.25	2.5	15.6(2)
" "	---	---	---	---	---	15.3(1)

(1) Sample broke outside gage length.
(2) Sample broke in head, test finished in file grips.
(3) 0.050-inch gage sheet prepared from 30-pound ingot.

TABLE LXVIII (Continued)

Heat Treatment	UTS Kpsi	K	% Elongation Local	Uniform	in 2-inches	Modulus (Ex10-^{6}psi)
1500F(10min)WQ+950F(1hr)AC	147	146	45	0	3.5	13.4
" "	147	146	40	0	7	13.4
" +950F(2hrs)AC	147	146	30	5.0	9.5	13.3
" "	153	151	45	15.0	21.5	13.4
" +950F(4hrs)AC	155	153	30	8.75	15.5	13.8
" "	156	155	5	6.25	7.5	13.7
" +950F(8hrs)AC	179	169	---	---	---	14.6(1)
" "	175	172	10	1.25	4	14.3
" +950F(16hrs)AC	201	189	20	5.0	9.5	15.5
" "	186	175	15	2.5	6	14.4(1)
" +950F(24hrs)AC	205	192	5	0	1	15.7
" "	---	---	---	---	---	15.3(1)
" +1000F(1hr)AC	153	151	30	11.25	16	13.9
" "	147	147	20	0	6	13.6(1)
" +1000F(2hrs)AC	153	151	25	3.75	12	13.8
" "	153	150	20	2.5	7.5	13.8
" +1000F(4hrs)AC	157	154	20	3.75	8.5	14.0
" "	154	146	25	11.25	16	13.4
" +1000F(8hrs)AC	179	167	20	7.5	9.5	14.5
" "	181	170	35	7.5	13	14.9
" +1000F(12hrs)AC	187	179	30	1.25	6.5	15.3(1)
" "	185	175	30	5.0	11	15.1
" +1000F(16hrs)AC	198	---	---	---	---	16.3(1)
" "	197	189	25	0	5	14.9(2)

(1) Sample broke outside gage length.
(2) Sample broke in head, test finished in file grips.
(3) 0.050-inch gage sheet prepared from 30-pound ingot.

TABLE LXIX

TENSILE PROPERTIES OF Ti-17V-7.5Co-3Al SHEET ALLOY, INGOT NO. V-2920

Heat Treatment	UTS Kpsi	YS Kpsi	% Elongation Local	Uniform	In 2-inches	Modulus (Ex10-6psi)
1500F(10min)WQ	149	147	30	1.25	5.5	12.7(1)
"	151	148	55	13.75	23	13.0
" +800F(1hr)AC	154	153	5	0	1.5	13.3(1)(2)
" "	153	151	20	1.25	3	13.2(1)
" +800F(8hrs)AC	192	179	10	1.25	3.5	13.8(2)
" "	193	182	10	1.25	3.5	13.9(1)
" +800F(16hrs)AC	214	211	---	---	---	15.1(1)(3)
" "	224	214	5	1.25	3	15.0(2)(3)
" +800F(24hrs)AC	227	223	5	0	0.5	15.3(1)(3)
" "	222	218	5	0	0.5	15.1(1)(3)
" +850F(1hr)AC	152	149	50	13.75	20	13.[illegible]
" "	152	148	40	5.0	10	13.5(1)
" +850F(4hrs)AC	174	172	10	0	2.5	13.9(1)(2)
" "	172	168	10	0	2	13.9(1)
" +850F(8hrs)AC	184	181	20	0	2.5	14.2(1)
" "	187	180	20	0	3.5	14.5(1)
" +850F(16hrs)AC	207	201	5	0	0.5	14.9(2)
" "	206	200	20	0	3	12.3(1)(2)
" +850F(24hrs)AC	229	217	10	1.25	3	15.2(1)
" "	220	215	---	---	---	14.7(1)(2)
" +900F(1hr)AC	152	148	20	7.5	14.5	13.4
" "	155	153	20	0	6	13.3(1)
" +900F(2hrs)AC	176	172	20	0	4	14.2(1)
" "	177	171	20	0	5	13.7(1)
" +900F(4hrs)AC	189	180	5	1.25	2.5	14.1
" "	193	183	5	1.25	3.5	14.6(1)
" +900F(6hrs)AC	193	186	20	1.25	1.5	14.6
" "	198	187	10	2.5	6	14.2(1)
" +900F(8hrs)AC	210	199	5	1.25	2.5	14.9(2)

(1) Sample broke outside gage length.
(2) Sample broke in head - test finished in file grips.
(3) Five other samples given the same heat treatment, broke before reaching yield stress.

TABLE LXIX (Continued)

Heat Treatment	UTS Kpsi	YS Kpsi	% Elongation Local	Uniform	in 2-inches	Modulus ($Ex10^{-6}$psi)
1500F(10min)WQ+900F(8hrs)AC	202	197	5	0	1	14.5(1)(2)
" +900F(16hrs)AC	213	203	5	1.25	2	14.9
" "	227	216	10	0	3	15.3 (2)
" +900F(24hrs)AC	220	207	10	3.75	4.5	15.4(1)(2)
" "	218	207	5	1.25	3	15.2(2)
" +950F(1hr)AC	149	146	20	1.25	8.5	13.3
" "	147	142	20	10.0	11.5	13.2(2)
" +950F(2hrs)AC	167	166	---	---	---	14.0(2)
" "	168	162	5	1.25	4	14.2
" +950F(4hrs)AC	168	160	20	3.75	8.5	13.9
" "	167	161	5	1.25	1.5	13.7(1)
" +950F(6hrs)AC	190	181	5	1.25	2	14.6(2)
" "	170	164	5	0	1.5	14.3
" +950F(8hrs)AC	198	196	5	0	0	14.8(2)
" "	206	190	20	1.25	5	14.7
" +950F(16hrs)AC	213	198	10	0	3.5	14.9(2)
" "	212	199	10	1.25	4.5	15.0(2)
" +950F(24hrs)AC	195	182	15	3.75	8	14.3
" "	197	184	15	3.75	8	15.1
" +1000F(1hr)AC	162	162	5	0	2.5	13.4(1)(2)
" "	157	153	5	0	0.5	13.6(1)
" +1000F(2hrs)AC	173	167	5	5.0	5	14.1(2)
" "	167	160	10	0	4	13.9(1)
" +1000F(4hrs)AC	189	176	10	5	6.5	12.1
" "	183	173	20	1.25	5	14.6(1)
" +1000F(8hrs)AC	190	179	5	1.25	3	15.1(2)
" "	189	---	---	---	---	13.8(1)(2)
" +1000F(16hrs)AC	199	190	10	2.5	4	14.9(2)
" "	---	---	---	---	---	14.5(1)(2)

(1) Sample broke outside gage length.
(2) Sample broke in head test finished in file grips.
(3) Five other samples given the same heat treatment, broke before reaching yield stress.
(4) 0.050-inch gage sheet, prepared from 30-pound ingot.

TABLE LXX

HARDNESS AND TENSILE PROPERTIES OF Ti-17V-2Fe-2Co-3Al, HEAT NO. V-2858

Heat Treatment		Vickers Hardness (10Kg Load)	UTS Kpsi	YS Kpsi	Elongation, % Local	Elongation, % Uniform	Elongation, % in 2"	Modulus ($Ex10^{-6}$psi)
1500F(10min)WQ		286	122	116	60	6.25	15.5	11.2
"		293	125	120	55	11.25	22	11.9
"	+800F(1hr)AC	290	126	122	50	11.25	18	12.4
"	"	295	125	121	50	12.5	22	12.2
"	+800F(8hrs)AC	421	183	166	10	2.5	5	14.0
"	"	404	180	175	15	2.5	5	13.3
"	+800F(24hrs)AC	455	226	210	10	0	2	14.9(1)
"	"	439	224	208	5	1.25	3	14.8(1)
"	+850F(1hr)AC	---	123	119	55	3.75	15.5	12.2
"	"	298	123	120	45	1.25	12	12.1
"	+850F(8hrs)AC	414	187	173	10	1.25	2.5	14.2
"	"	360	167	149	15	2.5	4	13.2
"	+850F(24hrs)AC	444	218	205	10	2.5	4.5	15.1(1)
"	"	437	222	209	10	1.25	4	15.1(1)
"	+900F(1hr)AC	284	123	119	45	2.5	12	12.9
"	"	295	126	123	45	5.0	15.5	12.2
"	+900F(2hrs)AC	302	129	123	30	1.25	9.5	12.3
"	"	301	132	128	20	3.75	6.5	12.8(1)
"	+900F(4hrs)AC	329	153	140	10	1.25	3	13.2(1)
"	"	345	155	154	10	1.25	4.5	13.0(1)
"	+900F(8hrs)AC	414	197	180	10	3.75	7	14.9(1)
"	"	414	200	182	10	1.25	3	14.6(1)
"	+900F(16hrs)AC	420	202	187	15	1.25	5.5	15.3(1)
"	"	420	205	197	15	2.5	5	14.3(1)

(1) Sample broke in head, test finished in file grips.

TABLE LXX (Continued)

Heat Treatment	Vickers Hardness (10Kg Load)	UTS Kpsi	YS Kpsi	Local	Uniform	in 2"	Modulus (Ex10-6psi)
1500F(10min)WQ+900F(24hrs)AC	433	218	203	---	---	---	15.3(1)(2)
" "	435	220	204	15	2.5	5	15.1(1)
" +950F(1hr)AC	295	130	125	30	10	14.5	12.0
" "	295	129	124	25	12.5	16	12.3
" +950F(2hrs)AC	308	143	135	20	0	4	12.9(2)
" "	303	144	139	20	0	3	13.1(1)
" +950F(4hrs)AC	376	176	158	20	6.25	8.5	13.9
" "	370	175	173	15	4.5	6.5	13.8(1)
" +950F(8hrs)AC	395	188	173	20	6.25	9	14.7
" "	387	187	183	25	2.5	6.5	14.7(2)
" +950F(16hrs)AC	385	189	174	30	5.0	9.5	15.3(1)
" "	386	190	176	25	5.0	9	15.0
" +950F(24hrs)AC	---	189	176	25	2.5	8	15.1
" "	394	193	179	25	6.25	11	15.3

(1) Sample broke in head, test finished in file grips.
(2) Sample broke outside gage length.
(3) 0.050-inch gage sheet, prepared from 30-pound ingot.

TABLE LXXI

600F TENSILE PROPERTIES OF METASTABLE BETA SHEET ALLOYS(1)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Elongation % in 1" Local	Uniform	Total	Modulus ($Ex10^{-6}$psi)
V-2793	Ti-8Mo-8V-2Fe-3Al	1500F(15min)WQ+900F(8hrs)AC	171	140	20	0	5	----
"	"	"	165	142	10	0	4	14.4
"	"	"	168	142	10	2.5	5	14.8
"	"	"	166	146	5	0	3	----
"	"	1500F(15min)WQ+900F(24hrs)AC	170	154	20	1.25	3.5	13.6
"	"	"	172	156	20	1.25	3.5	15.3
"	"	"	169	151	30	1.25	4.5	13.7
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	159	131	20	5.0	10	13.9
"	"	"	161	137	20	2.5	6	13.3
"	"	"	155	129	20	2.5	7	12.4
"	"	1500F(10min)WQ+900F(24hrs)AC	193	173	10	0	4	----
"	"	"	194	173	5	0	2	16.4
"	"	"	191	168	5	2.5	3	16.0
V-2729	Ti-17V-4Fe-3Al	1500F(10mins)WQ+900F(8hrs)AC	152	---(2)	30	2.5	9	13.0
"	"	"	152	120	10	2.5	6	13.8
"	"	1500F(10mins)WQ+900F(24hrs)AC	177	158	10	0	3	15.0
"	"	"	178	154	10	2.5	4	15.0
V-2920	Ti-17V-7.5Co-3Al	1500F(10mins)WQ+900F(8hrs)AC	186	162	10	2.5	6	13.3
"	"	"	192	172	10	2.5	4	13.7
"	"	"	181	---(2)	10	2.5	4	14.6
"	"	"	188	---(2)	10	2.5	4	13.2
"	"	"	191	168	10	2.5	4	14.2

(1) 0.050-inch gage sheet prepared from 30-pound ingot.
(2) Extensometer slipped - yield not recorded.

TABLE LXXI (Continued)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Elongation in 1" Local	Uniform	Total	Modulus (Ex10-^{6}psi)
V2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(24hrs)AC	197	184	5	0	1	15.3
"	"	"	200	184	5	0	1	14.0
"	"	"	208	184	5	2.5	3	13.9
"	"	"	198	176	10	0	2	17.7
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10mins)WQ+900F(8hrs)AC	136	122	35	5	13	12.4
"	"	"	144	128	40	5	14	13.0
"	"	"	142	126	20	5	9	15.0
"	"	1500F(10mins)WQ+900F(24hrs)AC	185	153	20	2.5	8	16.3
"	"	"	184	160	20	2.5	8	14.2
"	"	"	175	153	40	5	14	17.7

(1) 0.050-inch gage sheet prepared from 30-pound ingot.
(2) Extensometer slipped - yield not recorded.

TABLE LXXII

PERCENTAGES OF ROOM TEMPERATURE YIELD STRENGTH RETAINED AT 600F, BY ALLOY AND HEAT TREATMENT

Alloy	Heat Treatment	RT Yield Strength Kpsi	600F Yield Strength Kpsi	% of RT Yield Strength Retained at 600F
Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	181	132	73
"	" +900F(24hrs)AC	203	171	84
Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	158	125	79
"	" +900F(24hrs)AC	203	155	76
Ti-17V-[illegible].5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	138	167	84
"	" +900F(24hrs)AC	207	182	88
Ti-17V-4Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	156	120	77
"	" +900F(24hrs)AC	184	156	85
Ti-8Mo-8V-2Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	180	142	79
"	" +900F(24hrs)AC	191	154	81

TABLE LXXIII

ROOM TEMPERATURE AND 600F NOTCH TENSILE PROPERTIES OF FIVE AGEABLE METASTABLE BETA SHEET ALLOYS(1)(2)

Ingot No.	Alloy	Heat Treatment	Test Temp °F	NTS Kpsi	Average	Smooth UTS Kpsi	Ratio NTS/UTS
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	RT	106)			
"	"	"	"	119)			
"	"	"	"	127)	120	200	0.60
"	"	"	"	121)			
			"	127)			
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(24hrs)AC	RT	127)			
"	"	"	"	132)			
"	"	"	"	129)	129.5	219	0.59
"	"	"	"	134)			
			"	126)			
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	RT	87)			
"	"	"	"	98)			
"	"	"	"	106)			
"	"	"	"	78)	87	160	0.54
"	"	"	"	71)			
"	"	"	"	83)			
"	"	"	"	83)			
			"	92)			
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(24hrs)AC	RT	107)			
"	"	"	"	81)			
"	"	"	"	95)			
"	"	"	"	102)	95	198	0.48
"	"	"	"	100)			
"	"	"	"	89)			
"	"	"	"	108)			
			"	81)			

(1) 0.050-inch gage sheet prepared from 30-pound ingots.
(2) K_t=8

TABLE LXXIII (Continued)

Ingot No.	Alloy	Heat Treatment	Test Temp °F	NTS Kpsi	Average	Smooth UTS Kpsi	Ratio NTS/UTS
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	RT	117)			
"	"	"	"	117)	115	205	0.56
"	"	"	"	110)			
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(24hrs)AC	RT	106)			
"	"	"	"	114)	107	218	0.49
"	"	"	"	101)			
V-2729	Ti-17V-4Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	RT	180)			
"	"	"	"	178)	177.8	175	1.01
"	"	"	"	176)			
"	"	"	"	180)			
"	"	"	"	175)			
V-2729	Ti-17V-4Fe-3Al	1500F(10min)WQ+900F(24hrs)AC	RT	135)			
"	"	"	"	135)			
"	"	"	"	160)	142.6	198	0.72
"	"	"	"	143)			
"	"	"	"	140)			
-2793	Ti-8Mo-8V-2Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	RT	167)			
"	"	"	"	177)			
"	"	"	"	172)	171.6	198	0.87
"	"	"	"	172)			
"	"	"	"	170)			
V-2793	Ti-8Mo-8V-2Fe-3Al	1500F(10min)WQ+900F(24hrs)AC	RT	169)			
"	"	"	"	155)			
"	"	"	"	169)	163.8	204	0.80
"	"	"	"	165)			
"	"	"	"	161)			

TABLE LXXIII (Continued)

Ingot No.	Alloy	Heat Treatment	Test Temp °F	NTS Kpsi	Average	Smooth UTS Kpsi	Ratio NTS/UTS
V-2729	Ti-17V-4Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	600	141)			
"	"	"	"	143)			
"	"	"	"	148)	145.2	152	0.95
"	"	"	"	146)			
"	"	"	"	148)			
V-2729	Ti-17V-4Fe-3Al	1500F(10min)WQ+900F(24hrs)AC	600	190)			
"	"	"	"	191)			
"	"	"	"	190)	191.0	177	1.08
"	"	"	"	192)			
"	"	"	"	192)			
V-2793	Ti-8Mo-8V-2Fe-3Al	1500F(10min)WQ+900F(8hrs)AC	600	186)			
"	"	"	"	184)			
"	"	"	"	185)	184.0	168	1.10
"	"	"	"	182)			
"	"	"	"	183)			
V-2793	Ti-8Mo-8V-2Fe-3Al	1500F(10min)WQ+900F(24hrs)AC	600	189)			
"	"	"	"	189)			
"	"	"	"	186)	187.6	170	1.10
"	"	"	"	188)			
"	"	"	"	186)			

TABLE LXXIII (Contin

Ingot No.	Alloy	Heat Treatment	Test Temp °F	NTS Kpsi	Average	Smooth UTS Kpsi	Ratio NTS/UTS
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(8hrs)AC	600	162)			
"	"	"	"	152)			
"	"	"	"	149)	161	159	1.02
"	"	"	"	167)			
			"	174)			
V-2858	Ti-17V-2Fe-2Co-3Al	1500F(10min)WQ+900F(24hrs)AC	"	166)			
"	"	"	"	161)			
"	"	"	"	165)	164	193	0.85
"	"	"	"	169)			
"	"	"	"	159)			
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	"	158)			
"	"	"	"	154)	156	142	1.10
"	"	"	"	156)			
V-2900	Ti-8Mo-8V-5Co-3Al	1500F(10min)WQ+900F(24hrs)AC	"	167)			
"	"	"	"	169)	167	182	0.92
"	"	"	"	164)			
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(8hrs)AC	"	153)			
"	"	"	"	156)	150	188	0.80
"	"	"	"	141)			
V-2920	Ti-17V-7.5Co-3Al	1500F(10min)WQ+900F(24hrs)AC	"	146)			
"	"	"	"	148)	148	200	0.74
"	"	"	"	149)			

TABLE LXXIV

CREEP STABILITY PROPERTIES OF METASTABLE BETA SHEET ALLOYS IN THE AGED CONDITION

Heat Treatment	Exposure Temp °F	Exposure Stress Kpsi	Exposure Time Hours	% Def.	UTS Kpsi	YS Kpsi	% Elongation Local	% Elongation Uniform	% Elongation in 1"	Modulus (Ex10-6psi)
Ti-8Mo-8V-2Fe-3Al, Ingot V2793										
1500F-15mins-WQ+900F-8hrs-AC	---	---	---	---	197	180	12.5	2.0	5(1)	15.0
"	600	128	150	0.320	203	196	15	2.5	6	15.2
"	"	"	"	0.264	204	197	15	2.5	6	15.6
"	"	"	"	0.276	201	194	15	2.5	5	16.1
"	"	"	500	0.429	206	200	10	2.5	4	15.5
"	"	"	"	0.367	205	200	10	2.5	4	15.6
"	"	"	"	0.382	204	198	15	2.5	4	15.4
1500F-15mins-WQ+900F-24hrs-AC	---	---	---	---	204	191	10	2.5	5(1)	15.5
"	600	138	150	0.292	208	202	15	2.5	6	17.0
"	"	"	"	0.288	208	201	15	2.5	6	15.9
"	"	"	"	0.248	206	200	10	2.5	6	15.9
"	"	"	500	0.364	204	201	10	0	4	15.7
"	"	"	"	0.407	206	203	15	0	5	---(2)
"	"	"	"	0.396	204	197	5	5.0	6	16.4
Ti-17V-4Fe-3Al, Ingot V-2729										
1500F-10mins-WQ+900F-8hrs-AC	---	---	---	---	162	148	25	5.0	7.5(1)	13.9
"	600	108	150	0.444	163	151	10	2.5	4	13.5
"	"	"	"	0.516	162	151	15	2.5	9	13.4
"	"	"	"	0.500	178	---	---	---	---	14.1(3)
"	"	"	500	2.055	137	---	---	---	---	14.3(3)
"	"	"	"	2.040	153	---	---	---	---	14.7(3)
"	"	"	"	1.436	154	---	---	---	---	15.1(3)

(1) % in 2-inches.
(2) Stress-Strain curve not linear.
(3) Broke outside gage length.

TABLE LXXIV (Continued)

Heat Treatment	Exposure Temp °F	Exposure Stress Kpsi	Exposure Time Hours	% Def.	UTS Kpsi	YS Kpsi	% Elongation Local	% Elongation Uniform	% Elongation in 1"	Modulus ($Ex10^{-6}psi$)
Ti-17V-4Fe-3Al, Ingot V-2729										
1500F-10mins-WQ+900F-24hrs-AC	---	--	---	---	200	184	25	6.25	9(1)	15.6
"	600	14[illegible]	150	0.331	203	193	15	2.5	8	15.3
"	"	"	"	0.327	202	191	15	7.5	10	15.1
"	"	"	"	0.324	197	191	15	5.0	9	15.3
"	"	"	500	0.531	208	198	15	2.5	8	15.8
"	"	"	"	0.484	206	197	15	2.5	8	16.3
"	"	"	"	0.520	205	199	20	2.5	8	15.9
Ti-17V-2Fe-2Co-3Al, Ingot V-2858										
1500F-10mins-WQ+900F-8hrs-AC	---	---	---	---	197	180	10	3.75	7(1)	14.9
"	600	119	150	0.655	199	179	5	2.5	4	----(2)
"	"	"	"	0.971	200	195	5	0	2	13.4
"	"	"	"	0.611	202	182	10	0	4	14.3
"	"	"	500	2.564	171	---	---	---	---	15.3(3)
"	"	"	"	1.996	---	---	---	---	---	14.4(4)
"	"	"	"	2.615	169	---	---	---	---	14.7(3)
1500F-10mins-WQ+900F-24hrs-AC	---	---	---	---	220	204	15	2.5	5(1)	15.1
"	600	154	150	0.582	213	210	5	0	1	15.3
"	"	"	"	0.560	215	211	10	5.0	6	15.5
"	"	"	"	0.665	208	207	10	2.5	6	15.[illegible]
"	"	"	500	1.320	221	220	5	0	2	13.3
"	"	"	"	1.069	220	218	5	0	3	14.6
"	"	"	"	0.778	216	189	5	0	3	13.3

(1) % in 2-inches.
(2) Stress-Strain curve not linear.
(3) Broke outside gage length.
(4) Broke before reaching yield stress.

TABLE LXXIV (Continued)

Heat Treatment	Exposure Temp °F	Exposure Stress Kpsi	Exposure Time Hours	% Def.	UTS Kpsi	YS Kpsi	% Elongation Local	% Elongation Uniform	% Elongation in 1"	Modulus (Ex10-6psi)
Ti-8Mo-8V-5Co-3Al, Ingot V-2900										
1500F-10mins-WQ+900F-8hrs-AC	---	---	---	---	160	156	15	7.5	11(1)	13.7
"	600	113	150	0.164	156	152	5	2.5	3	13.8(5)
"	"	"	"	0.167	156	152	5	2.5	3	10.8(5)
"	"	"	"	0.160	167	161	10	2.5	5	13.8
"	"	"	500	0.164	151	---	---	---	---	14.5(3)(5)
"	"	"	"	0.185	155	---	---	---	---	13.9(3)
"	"	"	"	0.240	150	---	---	---	---	13.7(3)
1500F-10mins-WQ+900F-24hrs-AC	---	---	---	---	216	203	10	1.25	2.5(1)	15.6
"	600	140	150	0.171	186	---	---	---	---	15.0(3)
"	"	"	"	0.182	---	---	---	---	---	14.6(4)
"	"	"	"	0.200	193	190	5	0	1	11.7(5)
"	"	"	500	0.247	203	---	---	---	---	15.4(3)
"	"	"	"	0.218	198	---	---	---	---	15.9(3)(5)
"	"	"	"	0.280	207	---	---	---	---	16.3(3)(5)
Ti-17V-7.5Co-3Al, Ingot V-2920										
1500F-10mins-WQ+900F-8hrs-AC	---	---	---	---	209	208	5	0	1.5(1)	14.0(5)
"	600	150	150	0.353	206	199	---	---	---	14.9(3)(5)
"	"	"	"	0.240	203	199	5	0	1	15.6(5)
"	"	"	"	0.356	---	---	---	---	---	13.8(3)(4)(5)
"	"	"	500	0.415	197	---	---	---	---	15.1(3)(5)
"	"	"	"	0.404	153	---	---	---	---	15.8(3)(5)
"	"	"	"	0.371	162	---	---	---	---	15.6(3)(5)

(3) Broke outside gage length.
(4) Broke before reaching yield stress.
(5) Broke in head - test finished in file grips.

TABLE LXXIV (Continued)

Heat Treatment	Exposure Temp °F	Exposure Stress Kpsi	Exposure Time Hours	% Def.	UTS Kpsi	YS Kpsi	% Elongation Local	% Elongation Uniform	% Elongation in 1"	Modulus ($E \times 10^{-6}$ psi)
Ti-[illegible]V-[illegible].5Co-3Al, Ingot V-2920										
1500F-10mins-WQ+900F-24hrs-AC	---	---	---	---	218	207	10	3.75	4.5(1)	15.4(5)
"	600	164	150	0.255	220	213	5	2.5	3	15.5
"	"	"	"	0.516	216	---	---	---	---	15.8(3)
"	"	"	"	0.382	226	203	5	2.5	3	14.4(5)
"	"	"	500	0.687	---	---	---	---	---	16.1(3)(5)
"	"	"	"	0.684	202	---	---	---	---	15.9(3)
"	"	"	"	0.829	---	---	---	---	---	18.2(3)(5)

(3) Broke outside gage length.
(4) Broke before reaching yield stress.
(5) Broke in bend - test finished in file grips.
(6) 0.050-inch gage sheet prepared from 30-pound ingots.

TABLE LXXV

STRESS CORROSION TESTS ON SIX METASTABLE BETA SHEET ALLOYS(1)(2)

Ingot No.	Alloy	Bend Radius	Treatment	Result of Reverse Bending Until Flat
V-2858	Ti-17V-2Fe-2Co-3Al	6.2T	None (Control)	No Cracks
"	"	5.6T	800F(2hrs), No Salt	No Cracks
"	"	5.6T	800F(2hrs), Salt Coat	Small Cracks
"	"	5.4T	800F(2hrs), Salt Coat	Small Cracks
"	"	6.2T	800F(2hrs), Salt Coat	Small Cracks
V-2859	Ti-17V-4Fe-3Al	6.5T	None (Control)	No Cracks
"	"	6.5T	800F(2hrs), No Salt	No Cracks
"	"	6.5T	800F(2hrs), Salt Coat	No Cracks
"	"	6.5T	800F(2hrs), Salt Coat	No Cracks
"	"	6.5T	800F(2hrs), Salt Coat	Few Small Cracks
V-2860	Ti-8Mo-8V-2Fe-3Al	6.0T	None (Control)	No Cracks
"	"	6.0T	800F(2hrs), No Salt	No Cracks
"	"	5.6T	800F(2hrs), Salt Coat	No Cracks
"	"	5.7T	800F(2hrs), Salt Coat	No Cracks
"	"	6.0T	800F(2hrs), Salt Coat	No Cracks
V-2900	Ti-8Mo-8V-5Co-3Al	5.7T	None (Control)	No Cracks
"	"	6.0T	800F(2hrs), No Salt	No Cracks
"	"	5.7T	800F(2hrs), Salt Coat	Sample Broke
"	"	5.8T	800F(2hrs), Salt Coat	Sample Broke
"	"	6.3T	800F(2hrs), Salt Coat	Sample Broke
V-2920	Ti-17V-7.5Co-3Al	6.2T	None (Control)	No Cracks
"	"	6.3T	800F(2hrs), No Salt	No Cracks
"	"	5.7T	800F(2hrs), Salt Coat	Sample Broke
"	"	5.8T	800F(2hrs), Salt Coat	Sample Broke
D-3002	Ti-13V-11Cr-3Al	5.8T	None (Control)	No Cracks
"	"	5.8T	800F(2hrs), No Salt	No Cracks
"	"	5.8T	800F(2hrs), Salt Coat	Numerous Small Cracks
"	"	5.8T	800F(2hrs), Salt Coat	Numerous Small Cracks
"	"	5.8T	800F(2hrs), Salt Coat	Numerous Small Cracks

(1) Ti-13V-11Cr-3Al included as control.
(2) 0.050-inch gage sheet.

TABLE LXXVI

OXIDATION TESTS ON METASTABLE BETA SHEET ALLOYS(1)(2)

Ingot No.	Alloy	Test No.	Wt. Sample Grams	Wt. Sample + Crucible Before Exposure Grams	Wt. Sample + Crucible After Exposure Grams	Wt. Gain Grams	Wt. Gain Grams/Sq.Cm
V-2858	Ti-17V-2Fe-2Co-3Al	1	3.6530	34.3589	34.9273	0.5684)	
"	"	2	3.7234	31.4090	31.9685	0.5595)	0.0450 Average
"	"	3	3.4034	31.0788	31.6909	0.6121)	
V-2359	Ti-17V-4Fe-3Al	1	3.0305	34.5307	34.8696	0.3389)	
"	"	2	3.0223	30.7094	31.0484	0.3390)	0.0255 Average
"	"	3	3.2731	31.0529	31.3611	0.3082)	
V-2860	Ti-8Mo-8V-2Fe-3Al	1	3.2710	33.9733	34.0494	0.0761)	
"	"	2	3.5244	31.2082	31.3085	0.1003)	0.0061 Average
"	"	3	3.5167	31.1707	31.2309	0.0602)	
V-2900	Ti-8Mo-8V-5Co-3Al	1	4.3502	35.0244	35.1131	0.0887)	
"	"	2	[illegible].5128	32.1921	32.2680	0.0759)	0.0041 Average
"	"	3	4.4929	32.0712	32.1278	0.0566)	
V-2920	Ti-17V-7.5Co-3Al	1	3.6372	27.6895	27.8465	0.1570)	
"	"	2	3.6962	29.0907	29.2646	0.1739)	0.0147 Average
"	"	3	3.7646	31.9100	32.1460	0.2360)	

(1) All samples were exposed in an open crucible for 2 hours at 1500F.
(2) 0.050-inch gage sheet.

TABLE LXXVII

TENSILE PROPERTIES OF MACHINE WELDED SAMPLES OF THREE METASTABLE BETA ALLOYS(1)

Ingot No.	Alloy	Heat Treatment	UTS Kpsi	YS Kpsi	Local Elong. % (2)	Uniform Elong. %	Total Elong. in 2"	Total Elong. in ½"	Modulus ($E \times 10^{-6}$ psi)
V-2989	Ti-8Mo-8V-2Fe-3Al	1500F-10mins-AC+900F-16hrs-AC+Weld	127	123	35	0	3.5	16	15.7
"	"	"	125	122	35	0	3.5	16	14.8
"	"	"	124	121	40	0	4.5	18	14.9
"	"	"	128	126	25	0	4	14	15.4
"	"	"	129	127	30	0	4	16	15.2
"	"	"	129	126	35	0	4	18	15.2
"	"	"	126	124	45	0	3.5	16	14.8
"	"	"	121	121	5	0	0.5	2	14.2
		Average	126	124	30	0	3.5	14.5	15.0
V-2966	Ti-8Mo-8V-5Co-3Al	1500F-10mins-AC+900F-16hrs-AC+Weld	142	136	25	0	2.5	10	15.9
"	"	"	157	151	25	0	2.5	10	18.0
"	"	"	141	136	15	0	2	6	16.3
"	"	"	137	133	25	0	3	12	14.0
"	"	"	136	133	20	0	2	10	14.2
"	"	"	142	138	15	0	2	8	14.5
"	"	"	143	140	20	0	1.5	8	14.9
"	"	"	142	138	25	0	3.5	12	14.8
"	"	"	142	139	15	0	1.5	6	14.7
"	"	"	143	140	20	0	2.5	10	14.7
"	"	"	142	139	20	0	1.5	10	15.1
		Average	142	139	20	0	2.25	9.25	15.2
V-2967	Ti-17V-7.5Co-3Al	1500F-10mins-AC+900F-6hrs-AC+Weld	150	146	25	0	3	12	14.9
"	"	"	150	148	20	0	2	8	15.0
"	"	"	146	143	20	0	2	8	14.5
"	"	"	156	153	5	0	1	4	15.7
"	"	"	147	---	5	0	0	4	14.7
"	"	"	153	153	5	0	0	2	15.7
		Average	150	149	12.5	0	1.25	6.25	15.0

(1) 0.060-inch gage sheet
(2) Taken over 0.2-inch, which is approximate width of weld.

TABLE LXXVIII

COMPARISON OF PROPERTIES OF PHASE III METASTABLE BETA SHEET ALLOYS

Properties	Alloy: Ti-8Mo-8V-2Fe-3Al	Ti-17V-4Fe-3Al	Ti-17V-2Fe-2Co-3Al	Ti-8Mo-8V-5Co-3Al	Ti-17V-7.5C[illegible]
Measured Density lbs/cu in	0.175	0.172	0.172	0.178	0.176
Annealed Yield Strength, Kpsi	118-120	120-122	116-120	130-135	1[illegible]5-15[illegible]
Annealed Strength/Weight Ratio	680,000	705,000	685,000	740,000	840,000
Aged Yield Strength, Kpsi					
900F-8hrs Strength/Weight Ratio	180 - 4% elong 1,030,000	148 - 8% elong 860,000	180 - 5% elong 1,050,000	158 - 9% elong 890,000	198 - 2% e[illegible] 1,120,[illegible]
900F-16hrs Strength/Weight Ratio	186 - 6% elong 1,060,000	17[illegible] - 6% elong [illegible] 010,000	190 - 5% elong 1,100,000	176 - 3% elong 999,000	203 - 2% el[illegible] 1,170,[illegible]
900F-24hrs Strength/Weight Ratio	191 - 5% elong 1,090,000	184 - 9% elong 1,070,000	203 - 2% elong 1,200,000	200 - 2% elong 1,120,000	207 - 3% el[illegible] 1,210,[illegible]
Room Temperature Notch Tensile Strength (K_t=8), Kpsi					
900F-8hrs Age NTS/UTS Ratio	172 0.87	176 1.0	120 0.60	87 0.54	115 0.56
900F-24hrs Age NTS/UTS Ratio	164 0.83	143 0.72	130 0.59	95 0.51	107 0.49
600°F Aged Yield Strength, Kpsi					
900F-8hrs Age 900F-24hrs Age	142 154	120 156	132 171	125 155	167 182

TABLE LXXVIII (Continued)

Properties	Alloy: Ti-8Mo-8V-2Fe-3Al	Ti-17V-4Fe-3Al	Ti-17V-2Fe-2Co-3Al	Ti-8Mo-8V-5Co-3Al	Ti-17V-7.[illegible]
600F Notch Tensile Strength (K_t=8), Kpsi					
900F-8hrs Age	184	145	158	156	150
NTS/UTS Ratio	1.10	0.95	1.02	1.10	0.80
900F-24hrs Age	188	191	164	167	148
NTS/UTS Ratio	1.10	1.08	0.85	0.92	0.74
Creep Deformation at 600F ([illegible] of yield at 600F as load)					
900F-8hrs Age 150 hrs exposure	0.29%	0.49%	0.75%	0.16%	0.32%
900F-8hrs Age 500 hrs exposure	0.38%	1.84%	2.39%	0.19%	0.40%
900F-24hrs Age 150 hrs exposure	0.27%	0.32%	0.60%	0.185%	0.38%
900F-24hrs Age 500 hrs exposure	0.40%	0.51%	1.05%	0.25%	0.73%
Stress Corrosion Resistance (Salt Co[illegible] - Exposed 2 hr. at 600F with bend)					
Aged [illegible]F-24hrs AC (varied radius)	Good	Fair	Poor	-----	-----
Annealed [illegible]0F-10min-AC (6T radius)	Good	Good	Good	Poor	Poor
Oxidation Behavior (Gain in Weight After 2 hrs at [illegible]F, (m[illegible]sq.cm.)	0.0061	0.0255	0.0450	0.0041	0.0147

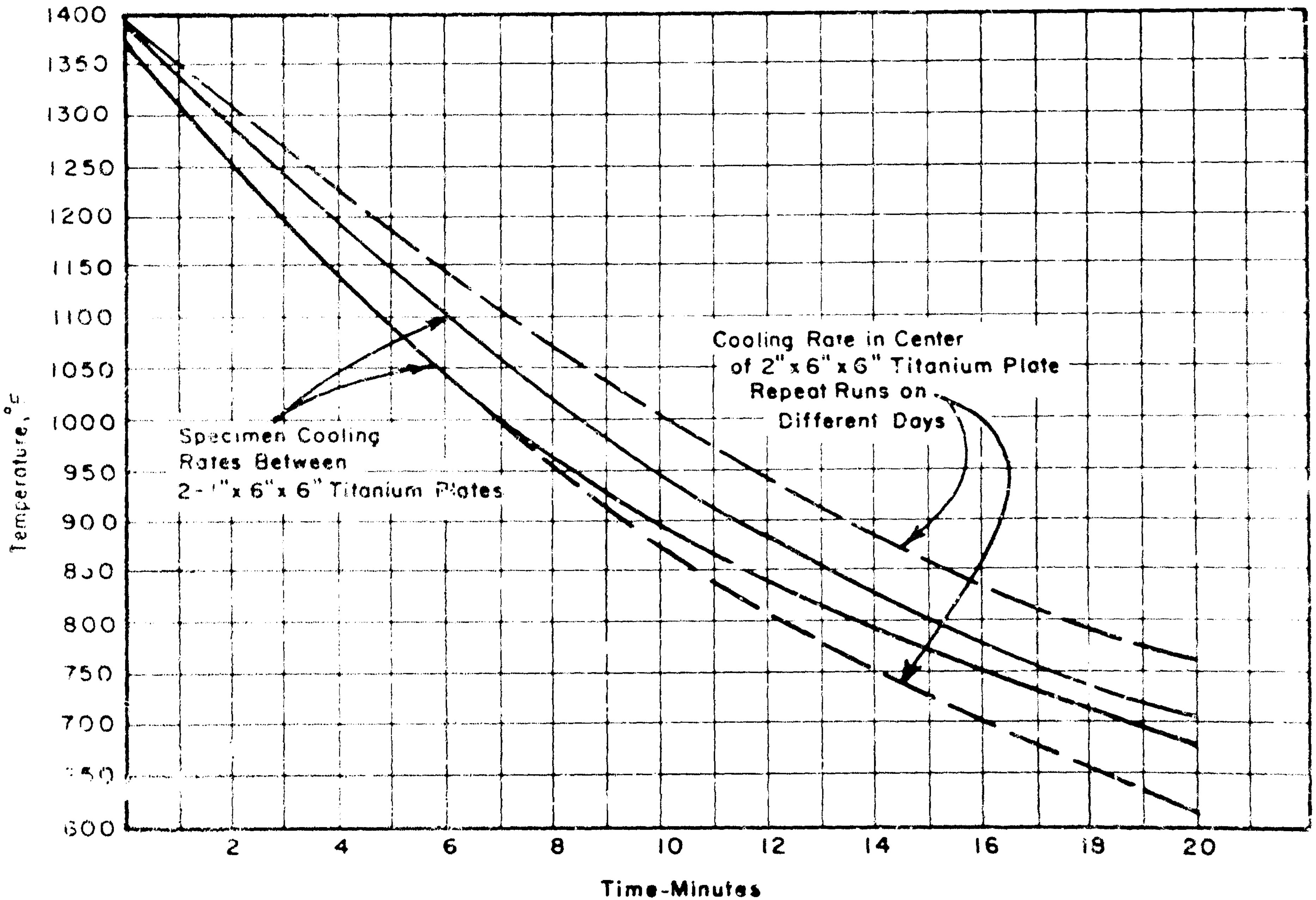


FIGURE I. COMPARISON OF SPECIMEN COOLING RATES TO THAT IN CENTER OF A 2" PLATE.

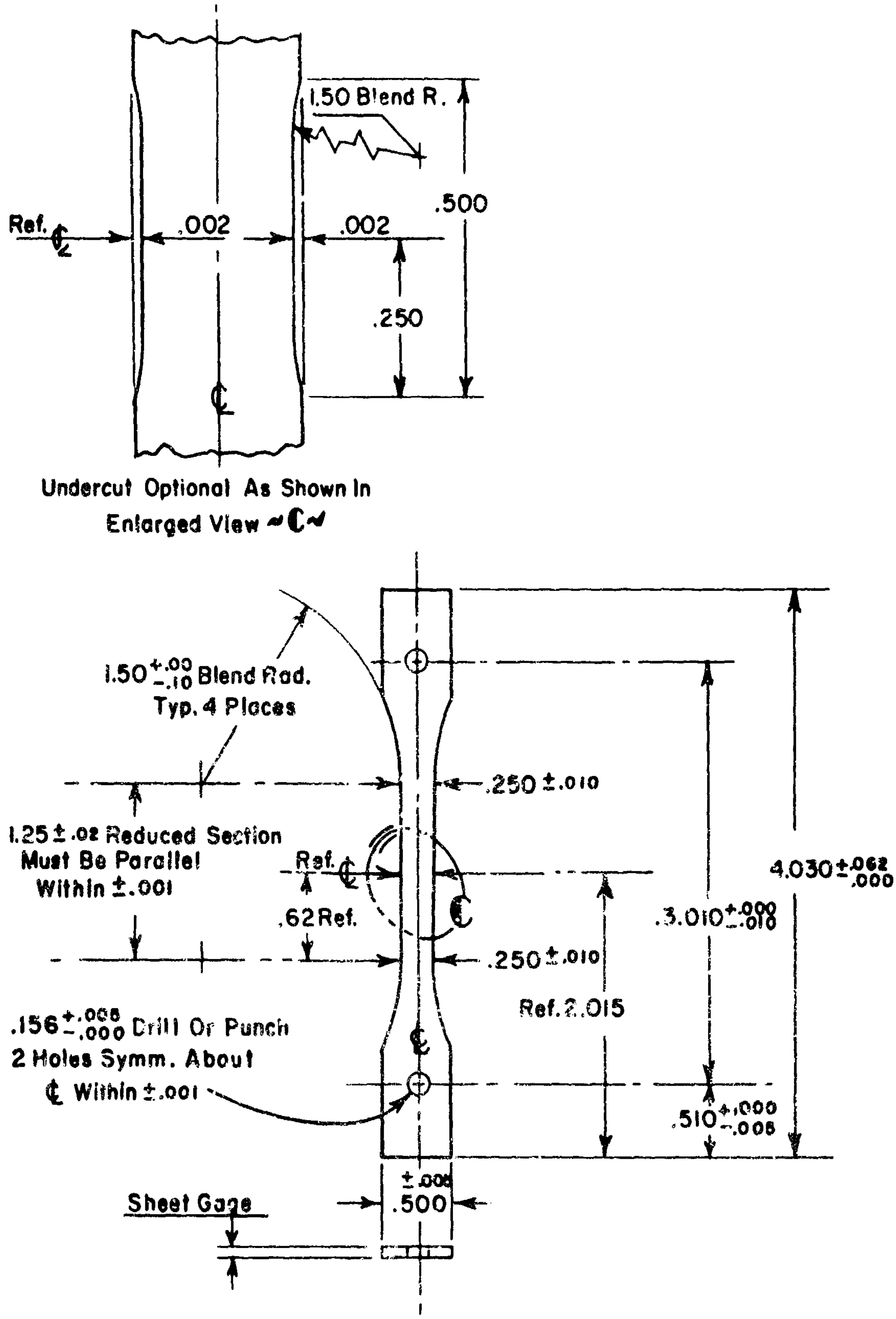


FIGURE 2. SHEET TENSILE SPECIMEN.

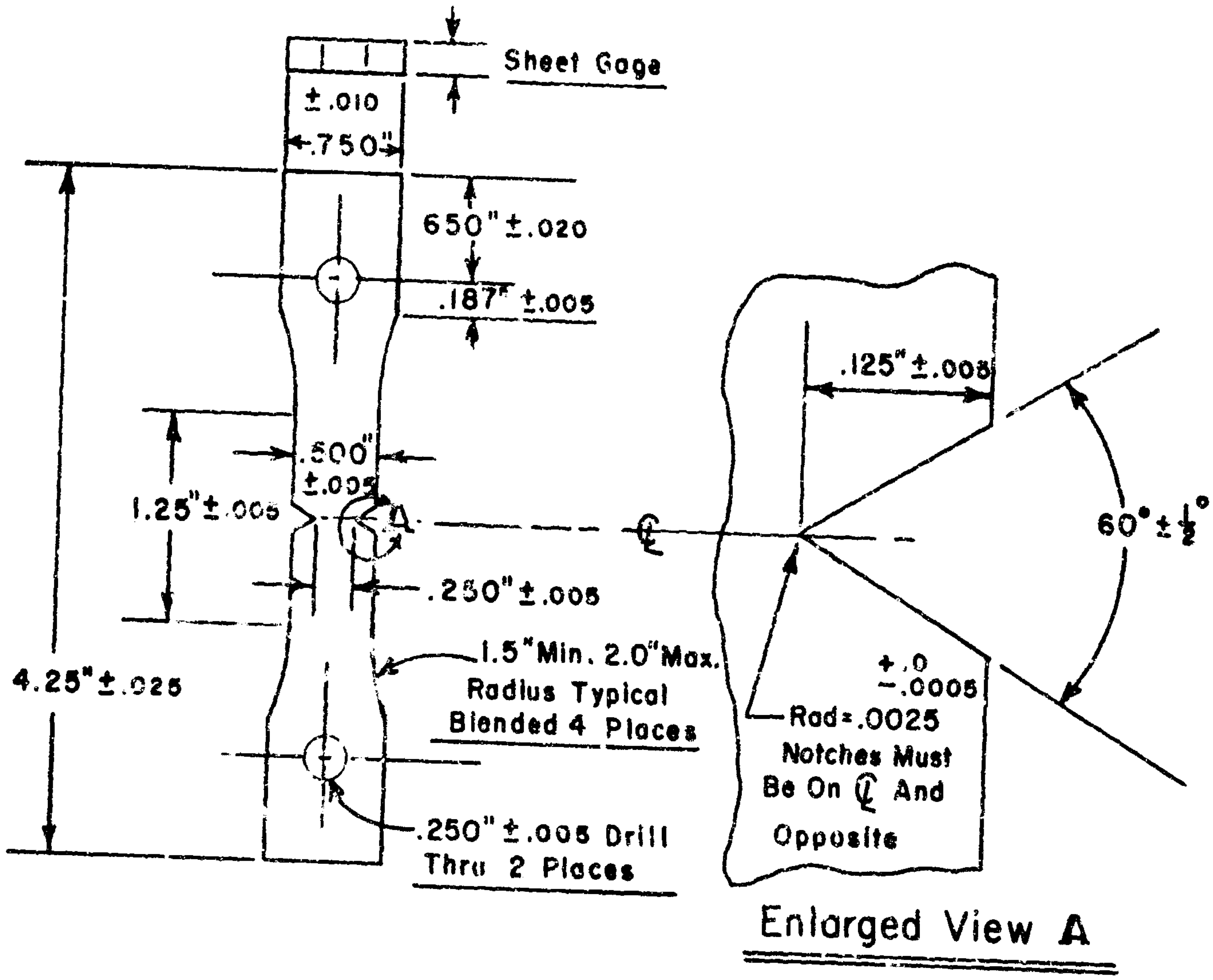


FIGURE 3. NOTCHED SHEET TENSILE SPECIMEN ($K_t = 8$)

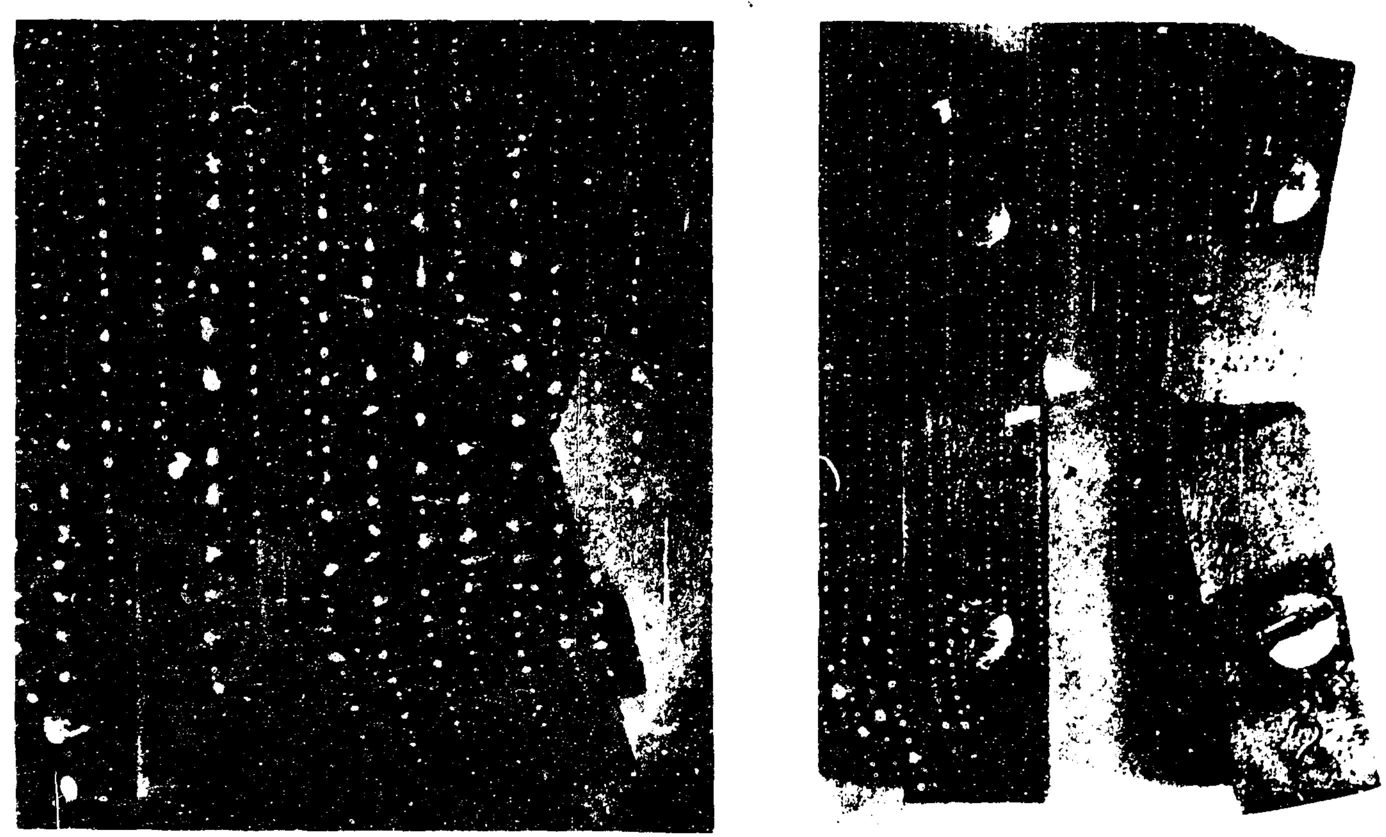
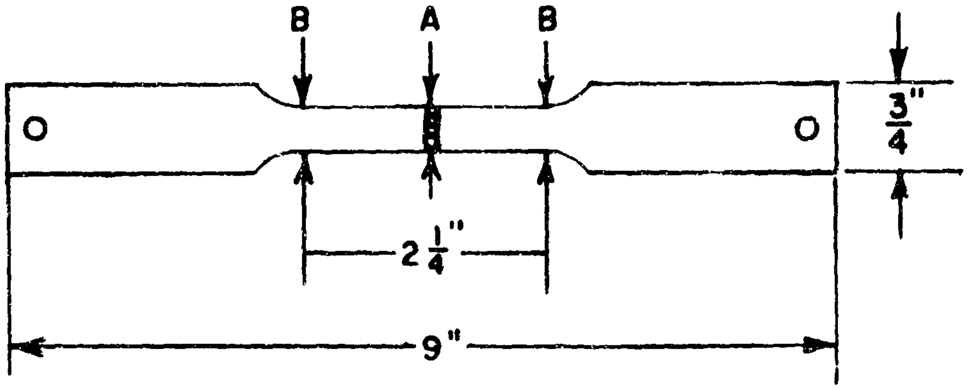


Figure 4. Face and Side Views of Laminated Charpy V Samples Showing Samples Before and After Testing.

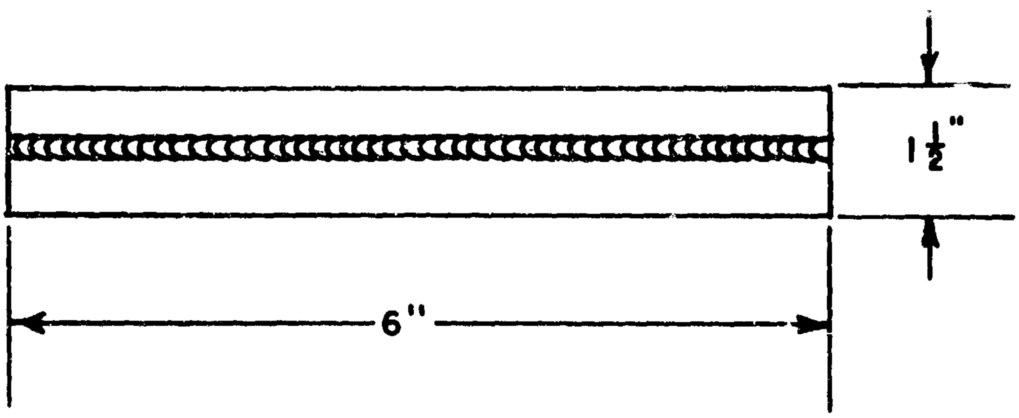


Dimension A = 0.505" Max. To 0.495" Min.

B = A + 0.003" To A + 0.005"

Weld to Be Ground Flush Using Coolant.

BUTT WELD TRANSVERSE TENSILE SPECIMEN



BUTT WELD BEND TEST SPECIMEN

FIGURE 5. WELDED TENSILE AND BEND SAMPLES.

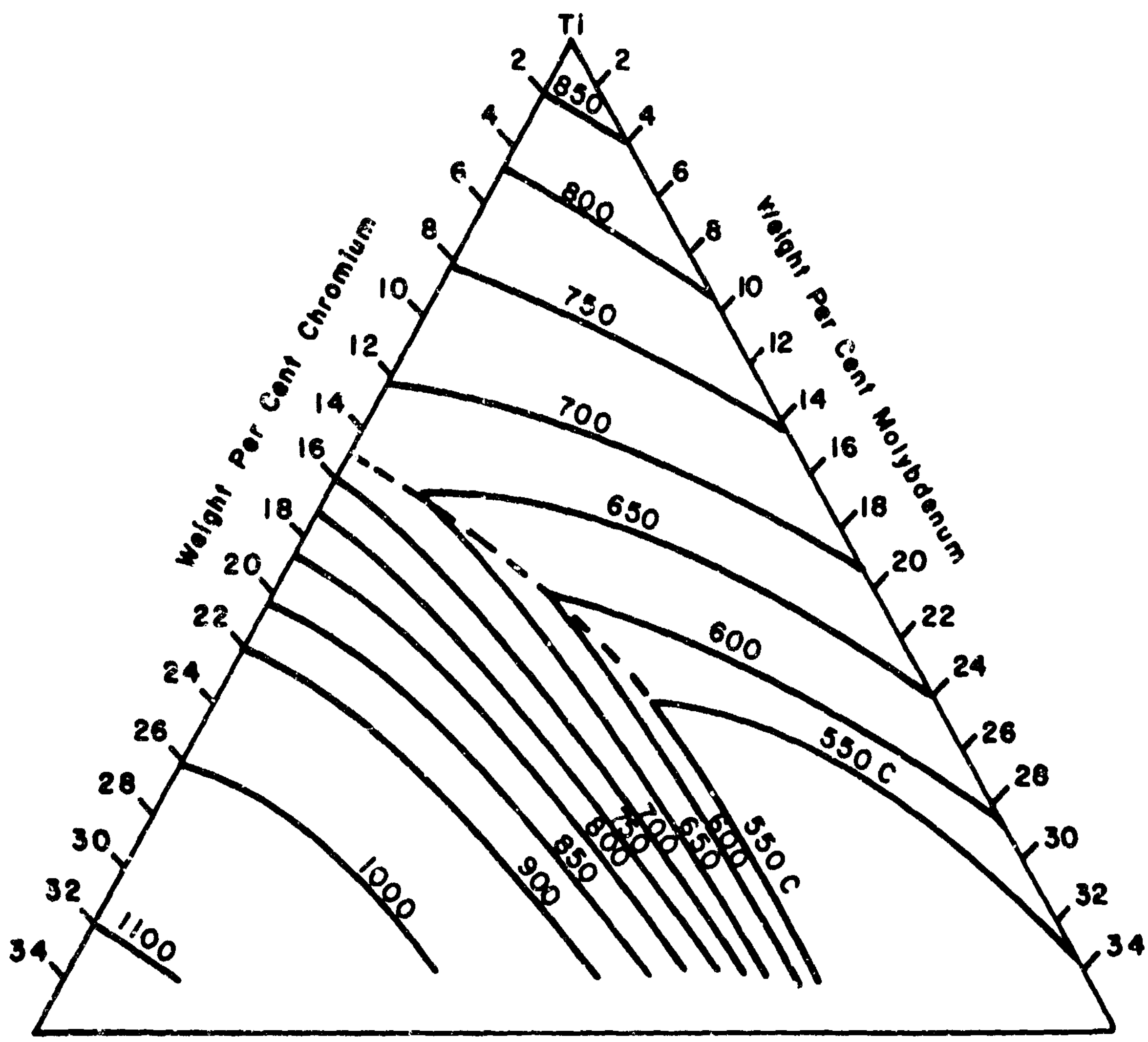


FIGURE 6. SUMMARY OF BETA SURFACE ISOTHERMS IN THE SYSTEM Ti-Cr-Mo.

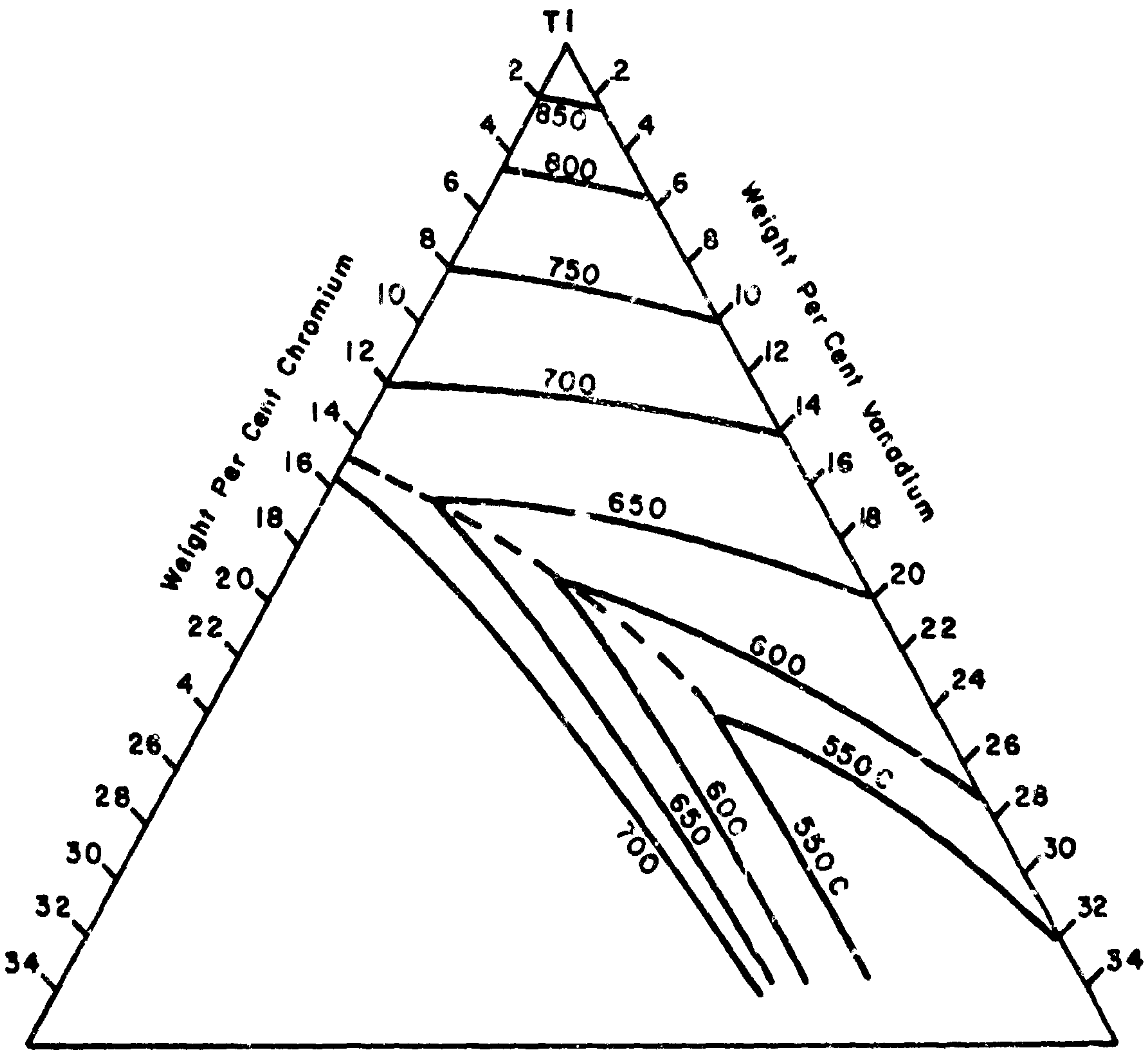


FIGURE 7. ESTIMATED BETA SURFACE ISOTHERMS IN THE SYSTEM Ti-Cr-V. BASED ON TIE LINE CONSTRUCTION AND ANALOGY TO Ti-Cr-Mo SYSTEM.

Ti-17V-5Cr-3Al

Ti-17V-7.5Cr-3Al

Ti-17V-10Cr-3Al

Ti-17V-12.5Cr-3Al

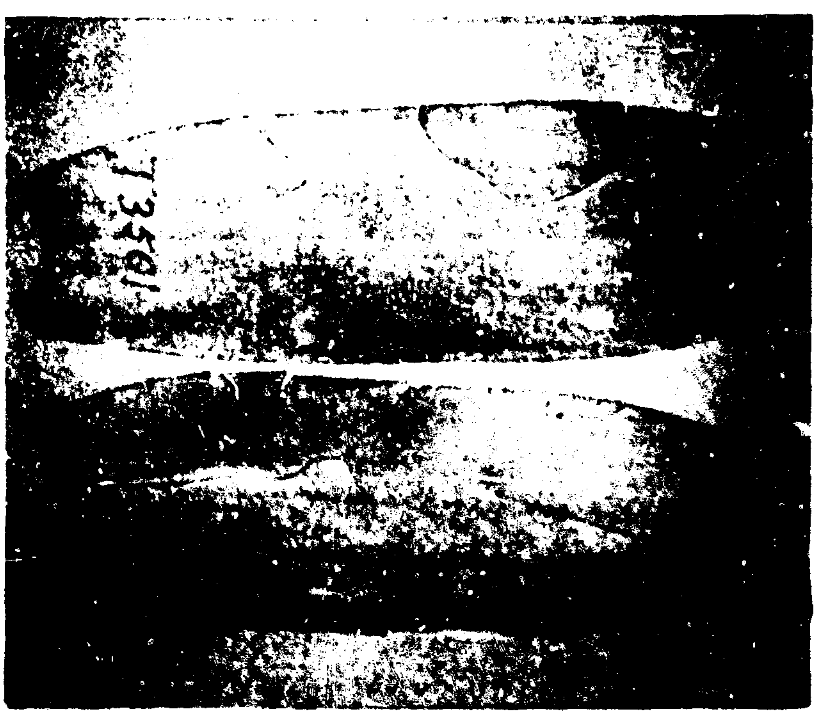
Ti-17V-15Cr-3Al

Figure 8A. Appearance Of Sheet After Cold Rolling.

Ti-17V-5Mn-3Al

Ti-17V-7.5Mn-3Al

Ti-17V-10Mn-3Al



Ti-17V-12.5Mn-3Al

Ti-17V-15Mn-3Al

Figure 8A (cont'd.). Appearance of Sheet After Cold Rolling.

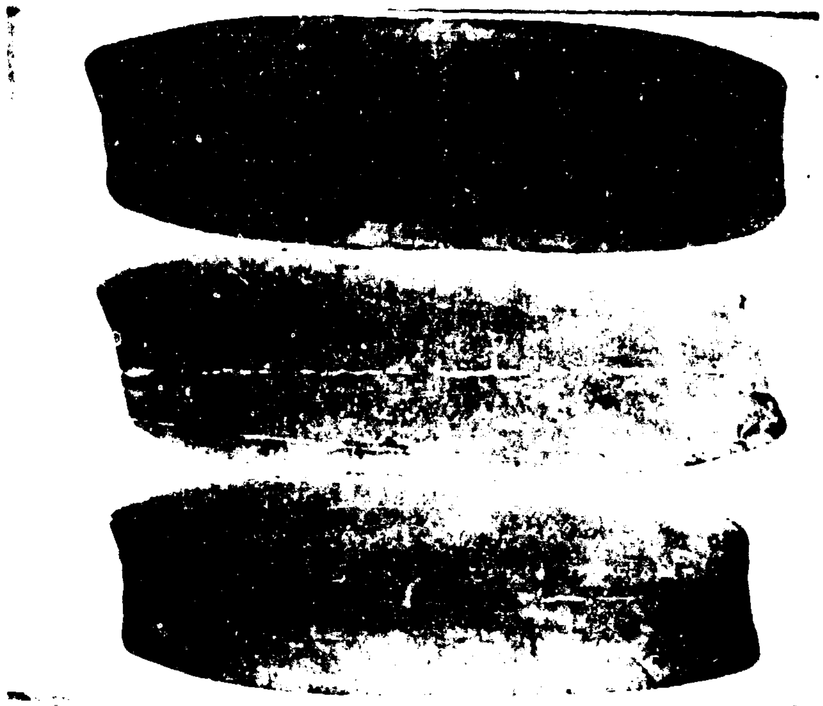


Figure 8A (cont'd.). Appearance Of Sheet After Cold Rolling.

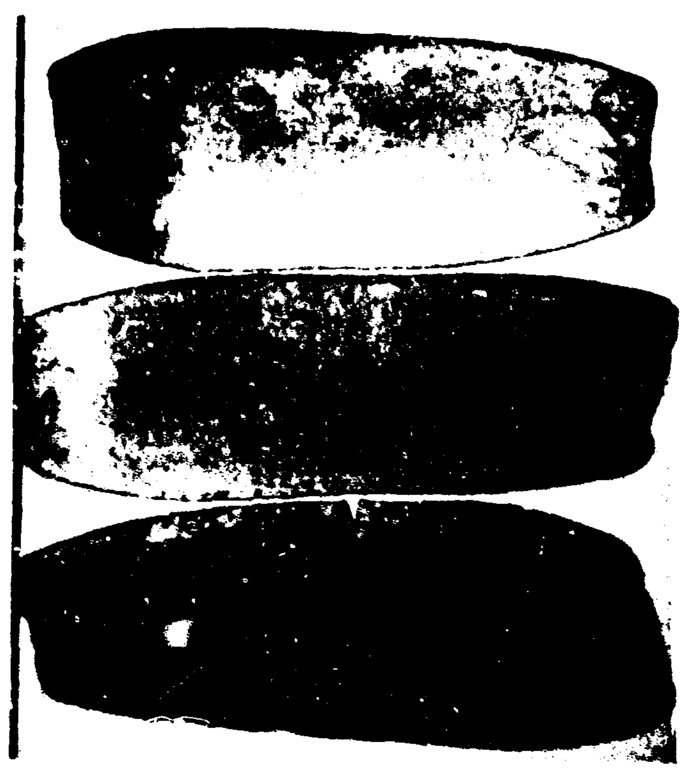


Figure 8B. Appearance of Sheet After Cold Rolling.

Ti-8Mo-8V-12.5Cr-3Al

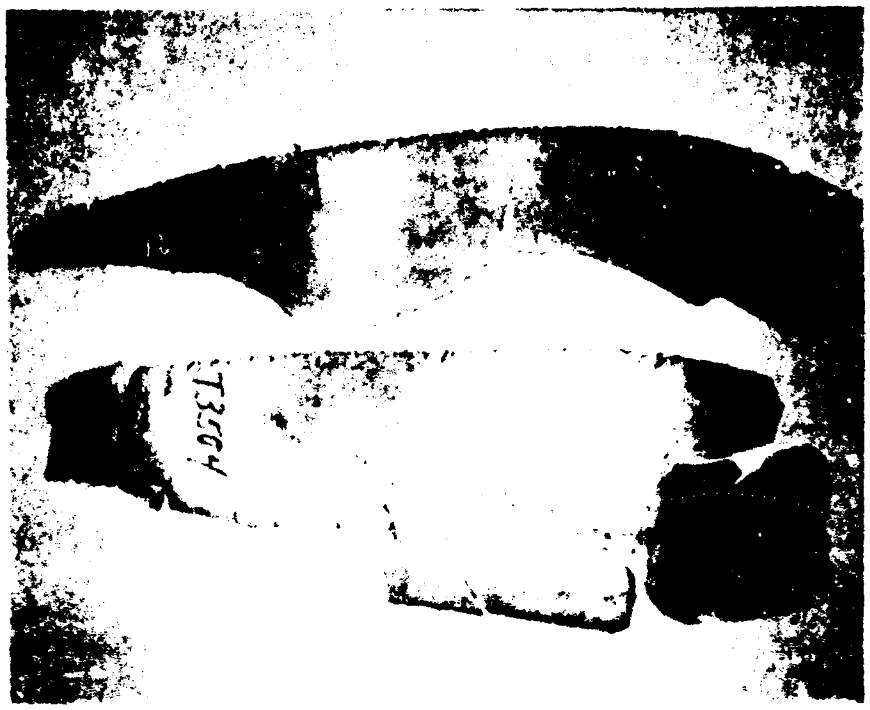
Ti-8Mo-8V-15Cr-3Al

Ti-8V-8Mo-5Mn-3Al

Ti-8V-8Mo-7.5Mn-3Al

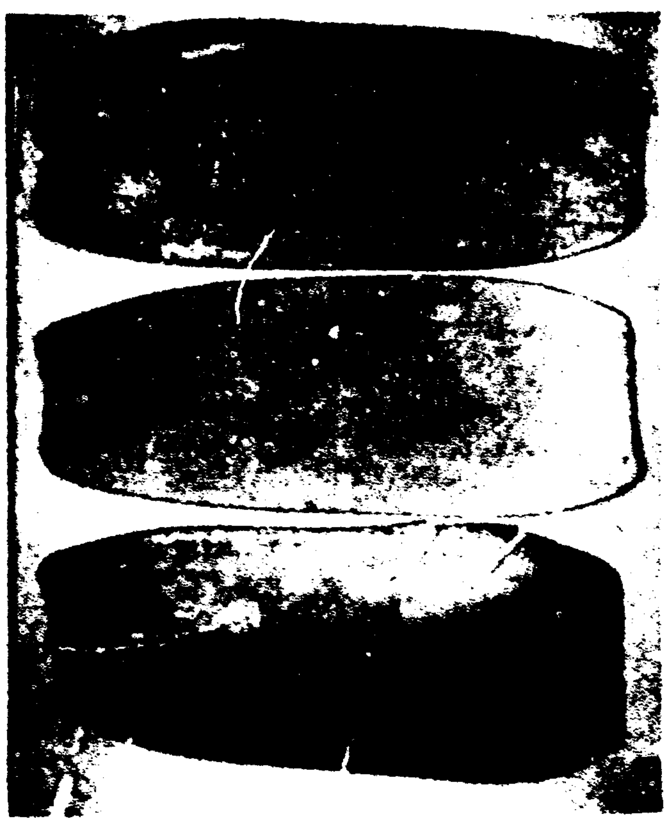
Ti-8V-8Mo-10Mn-3Al

Figure 9B (cont'd.). Appearance of Sheet After Cold Rolling.



Ti-8Mo-8V-12.5Mn-3Al

Ti-8Mo-8V-15Mn-3Al



Ti-8V-8Mo-2.5Fe-3Al

Ti-8V-8Mo-5Fe-3Al

Ti-8V-8Mo-7.5Fe-3Al

Figure 3B (cont'd.). Appearance of Sheet After Cold Rolling.

Ti-15Mo-5Cr-3Al

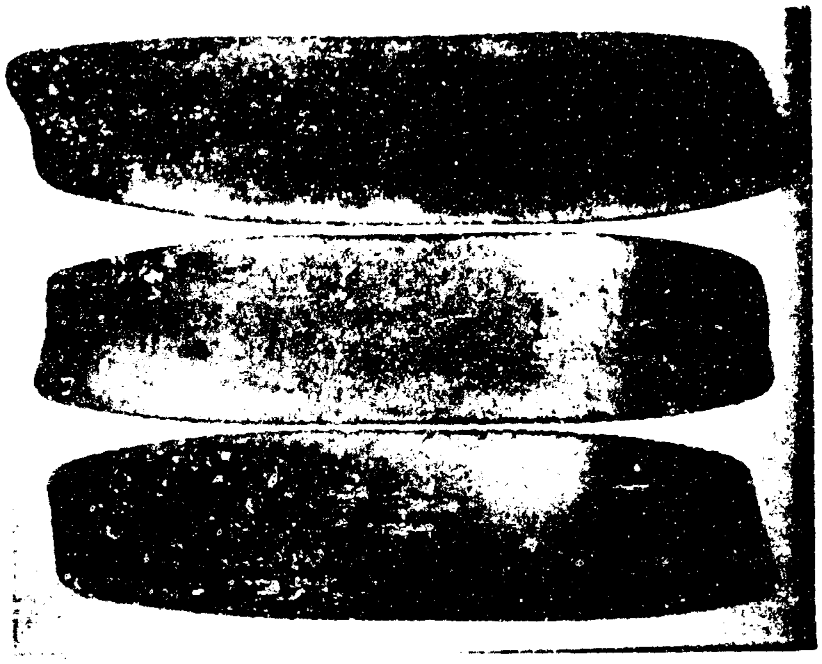
Ti-15Mo-7.5Cr-3Al

Ti-15Mo-10Cr-3Al

Ti-15Mo-12.5Cr-3Al

Ti-15Mo-15Cr-3Al

Figure 9C. Appearance of Sheet After Cold Rolling.



Ti-15Mo-5Mn-3Al

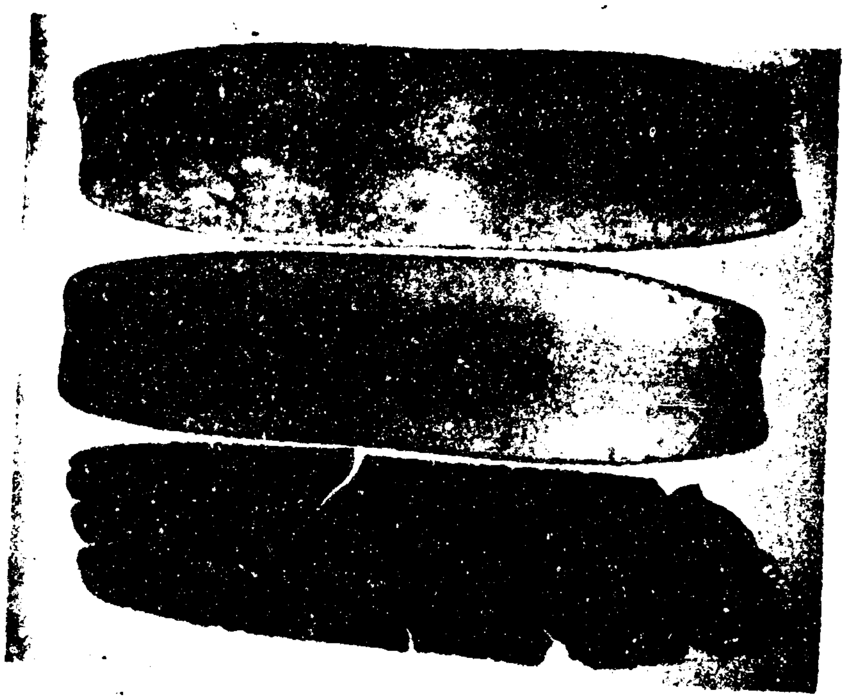
Ti-15Mo-7.5Mn-3Al

Ti-15Mo-10Mn-3Al

Ti-15Mo-12.5Mn-3Al

Ti-15Mo-15Mn-3Al

Figure 8C (cont'd.). Appearance of Sheet After Cold Rolling.



Ti-15Mo-2.5Fe-3Al

Ti-15Mo-5Fe-3Al

Ti-15Mo-7.5Fe-3Al

Figure 8C (cont'd.) Appearance of Sheet After Cold Rolling.

5053A 250X

Oxalic + Kroll Etch

Figure 9. T-3498, Ti-8Mo-8V-15Cr-3Al As-Rolled. Slip Bands In Distorted Beta Grains. A Few Particles Of Second Phase Present.

5055B 250X

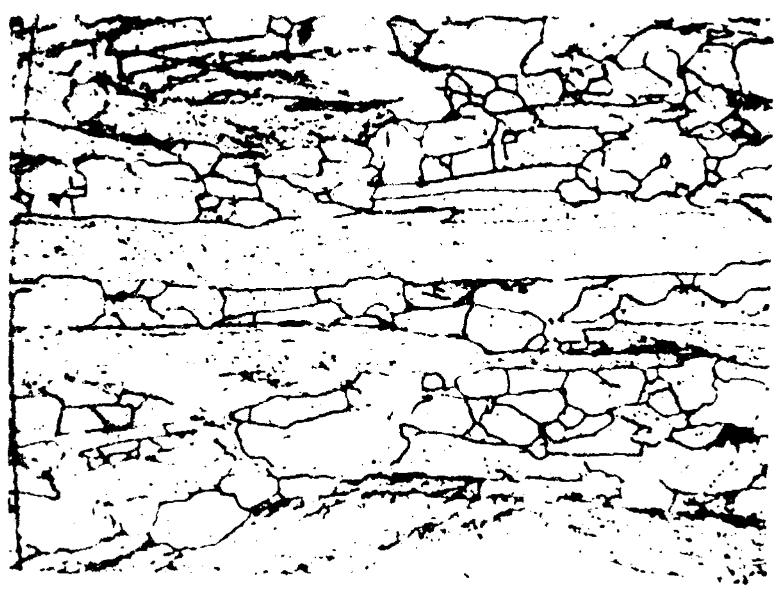
Oxalic + Kroll Etch

Figure 10. T-3500, Ti-15Mo-15Cr-3Al. Heat Treated ½-Hour At 1250F, Quenched. Unrecrystallized With Precipitate Mainly At Grain Boundaries.

4064D 250X

Oxalic + Kroll Etch

Figure 11. T-3318, Ti-15Mo-7.5Mn-3Al. Annealed 15 Minutes At 1350F, Slow Cooled. 60% Recrystallized Beta With Scattered Particles Of Second Phase. Uniform Elongation 25%; Total Elongation 30%; UTS 142,000 psi.



4064F 250X

Oxalic + Kroll Etch

Figure 12. T-3318, Ti-15Mo-7.5Mn-3Al. Heat Treated 15 Minutes At 1350F, Slow Cooled, Plus 8 Hours Age At 900F. Little Change in Microstructure. Uniform Elongation 15%; Total Elongation 22%; UTS 144,000 psi

4066D 250X

Oxalic + Kroll Etch

Figure 13. T-3323, Ti-17V-2.5Fe-3Al. Annealed 15 Minutes At 1350F, Slow Cooled. Partly Recrystallized With Second Phase At Former Grain Boundaries. Uniform Elongation 7.5%; Total Elongation 15%; UTS 120,000 psi.

4066F 250X

Oxalic + Kroll Etch

Figure 14. T-3323, Ti-17V-2.5Fe-3Al. Heat Treated 15 Minutes At 1350F, Slow Cooled, Plus 8 Hours Age at 900F. Heavy Precipitate (alpha + TiFe?) Within Grains. Uniform Elongation 5%; Total Elongation 7%; UTS 197,000 psi.

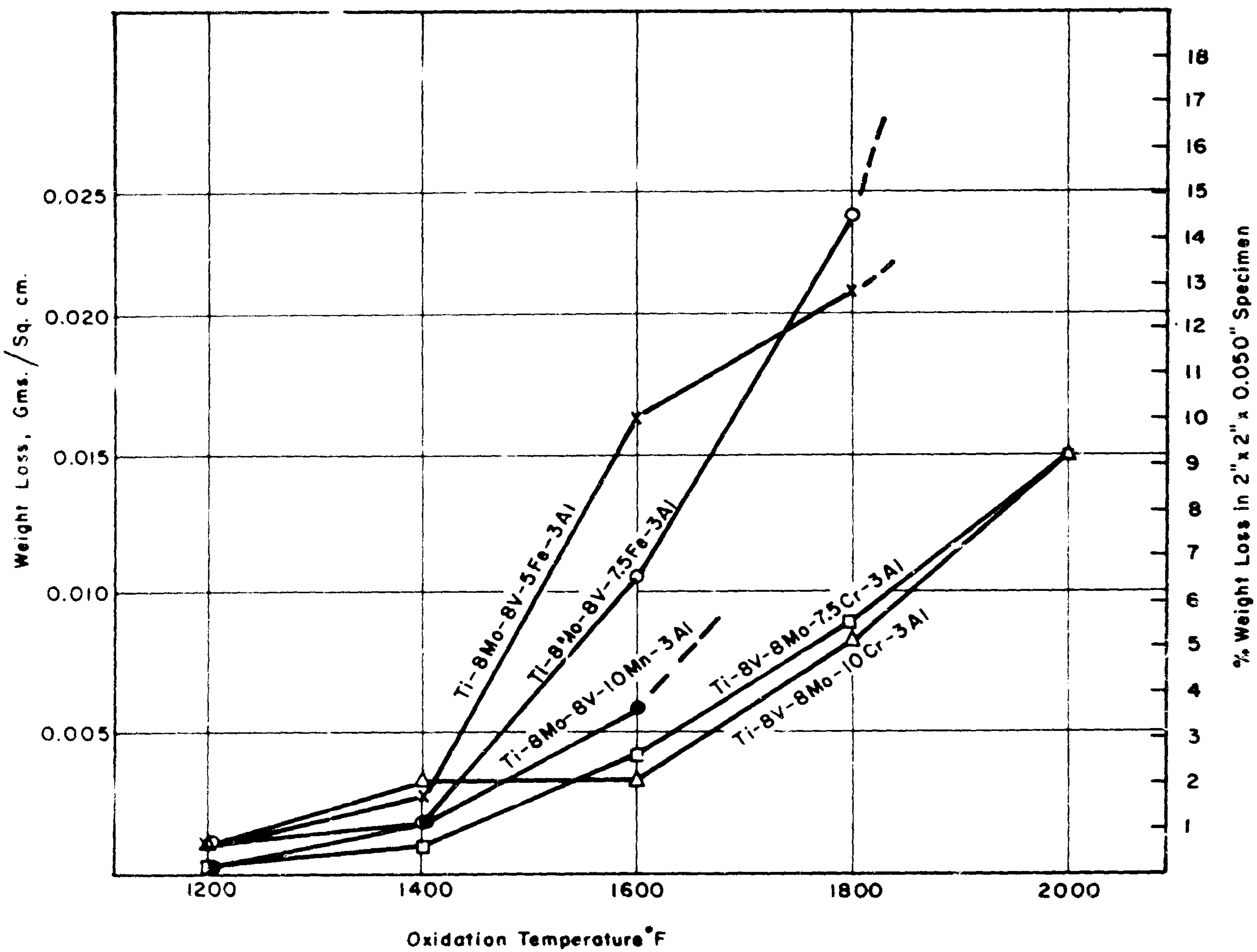


FIGURE 15. OXIDATION RATES FOR Ti-8V-8Mo-X-3Al ALLOYS AFTER 2 HOURS EXPOSURE.

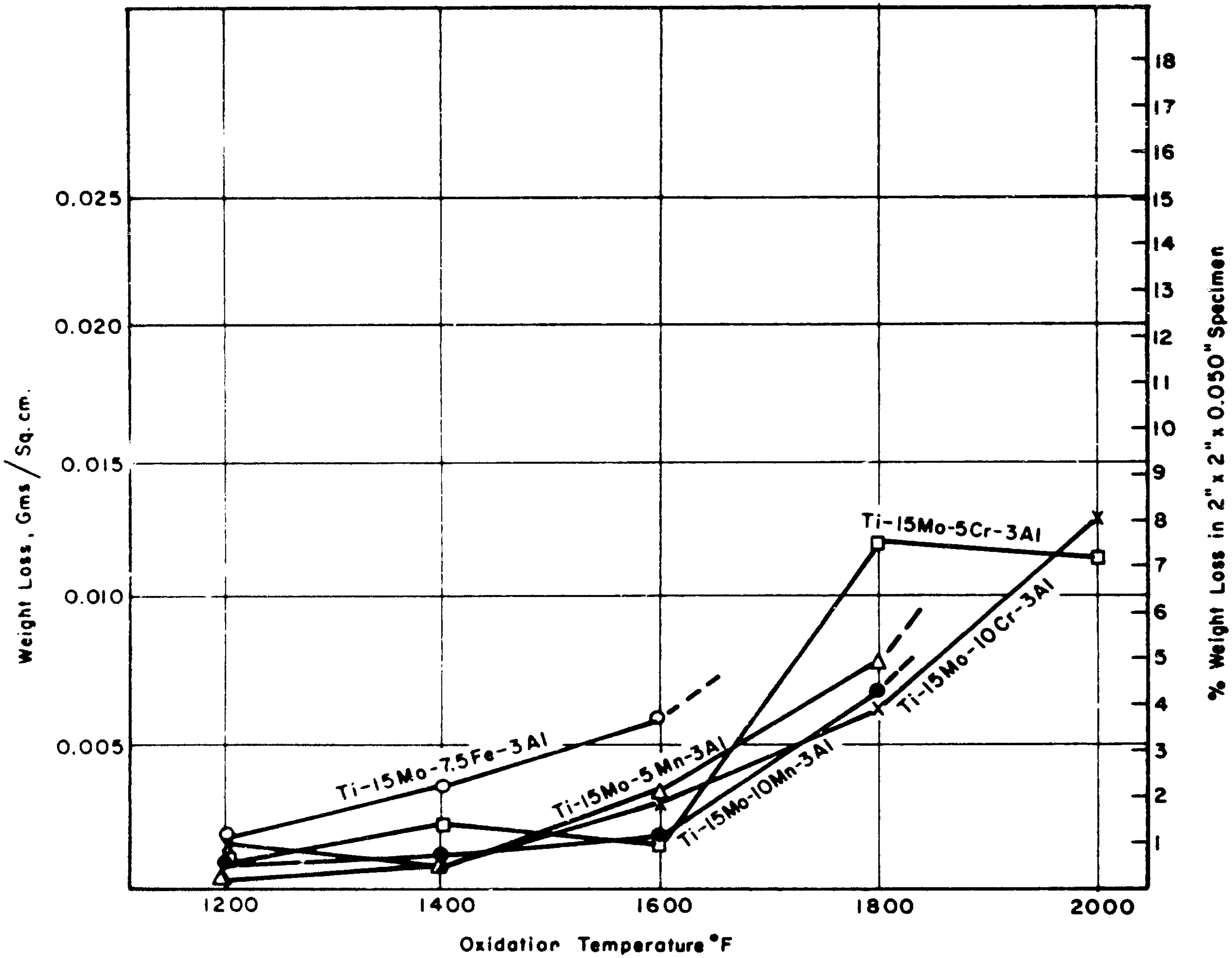


FIGURE 16. OXIDATION RATES FOR Ti-15Mo-X-3Al ALLOYS AFTER 2 HOURS EXPOSURE.

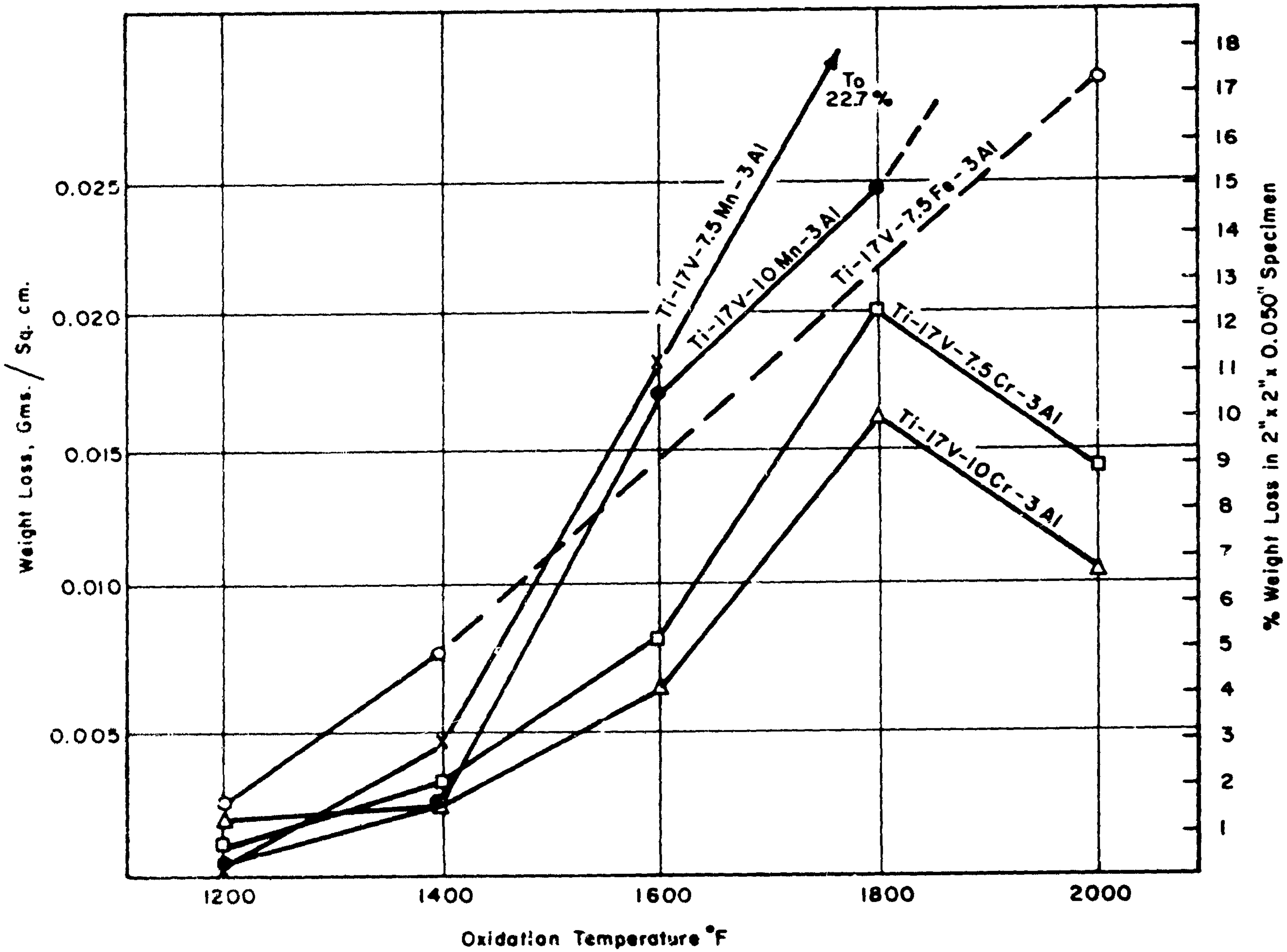


FIGURE 17. OXIDATION RATES FOR Ti-17V-X-3Al ALLOYS AFTER 2 HOURS EXPOSURE.

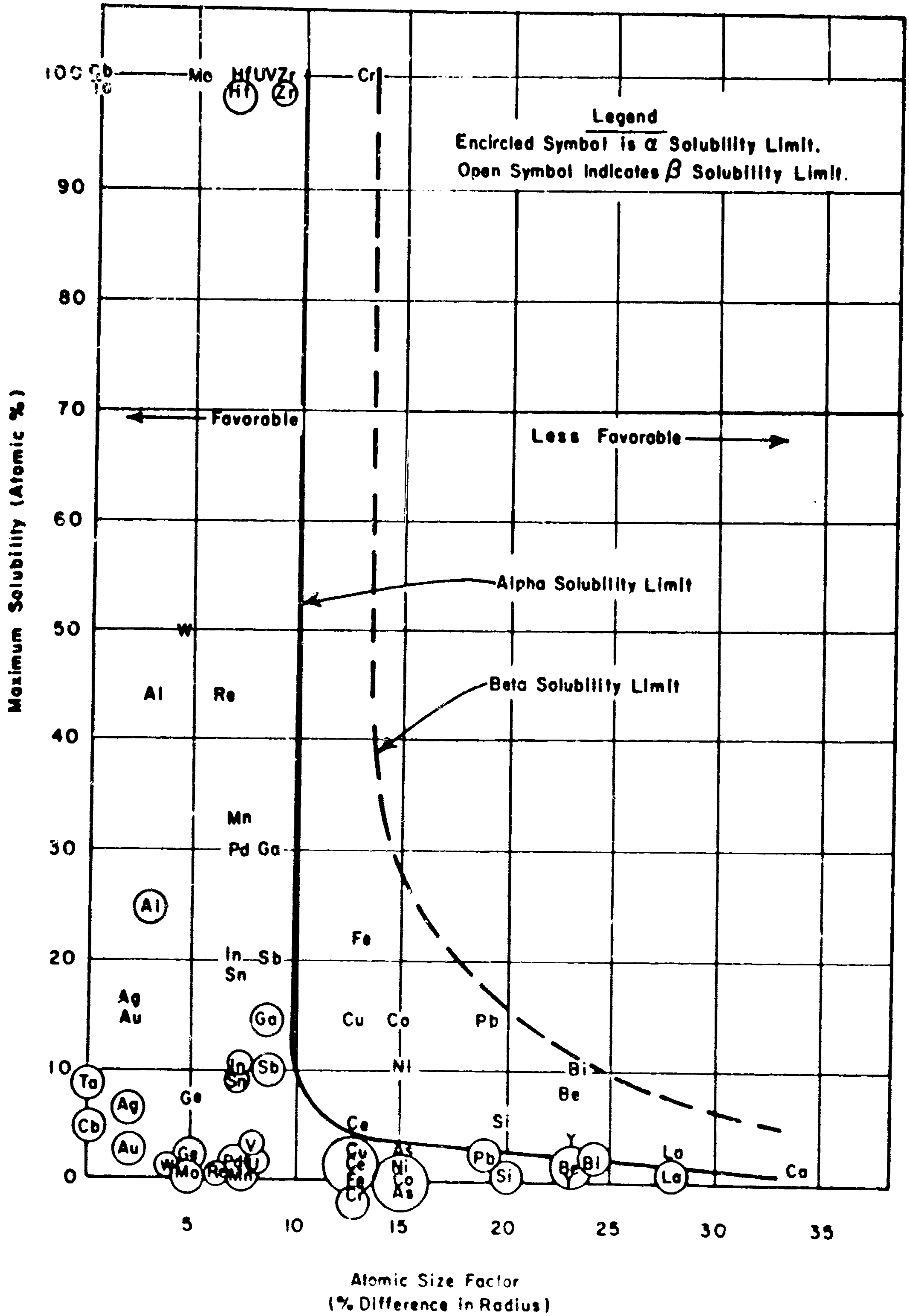


FIGURE 18. INFLUENCE OF SIZE FACTOR ON SOLID SOLUBILITY (SUBSTITUTIONAL ALLOYING) IN TITANIUM.

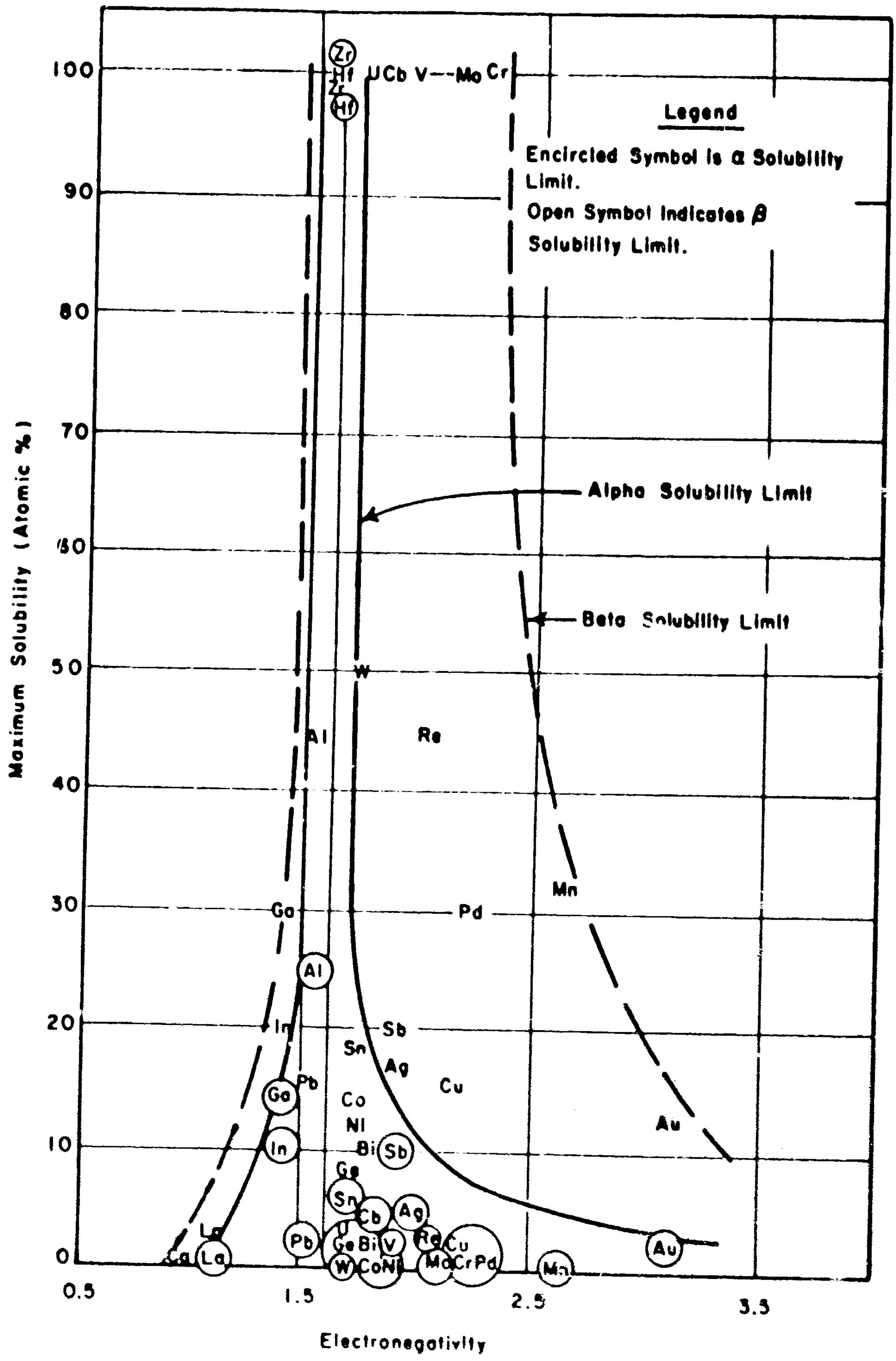
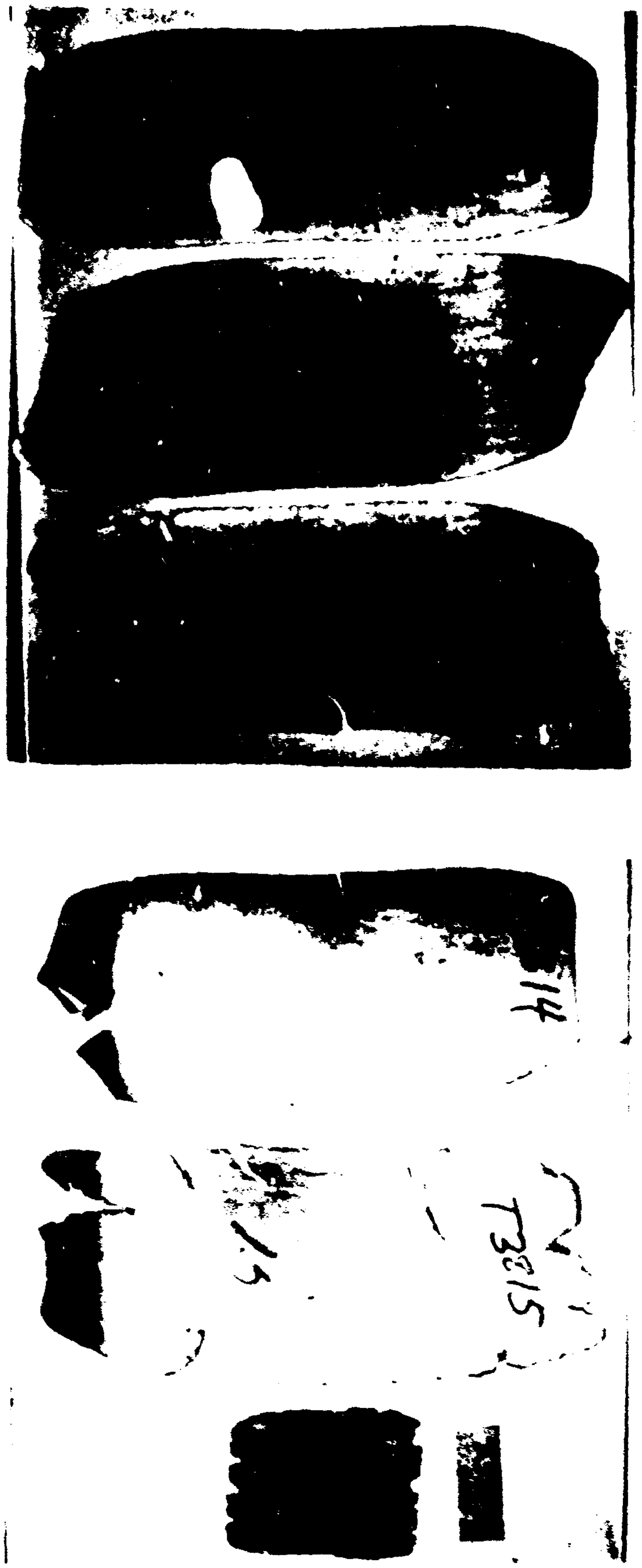


FIGURE 19. INFLUENCE OF ELECTRONEGATIVITY ON SOLID SOLUBILITY. (SUBSTITUTIONAL ALLOYING) IN TITANIUM.



T-3726
Ti-17V-10Cr-3Al-1Cu
Good Quality

T-3727
Ti-17V-10Cr-3Al-3Cu
Good Quality

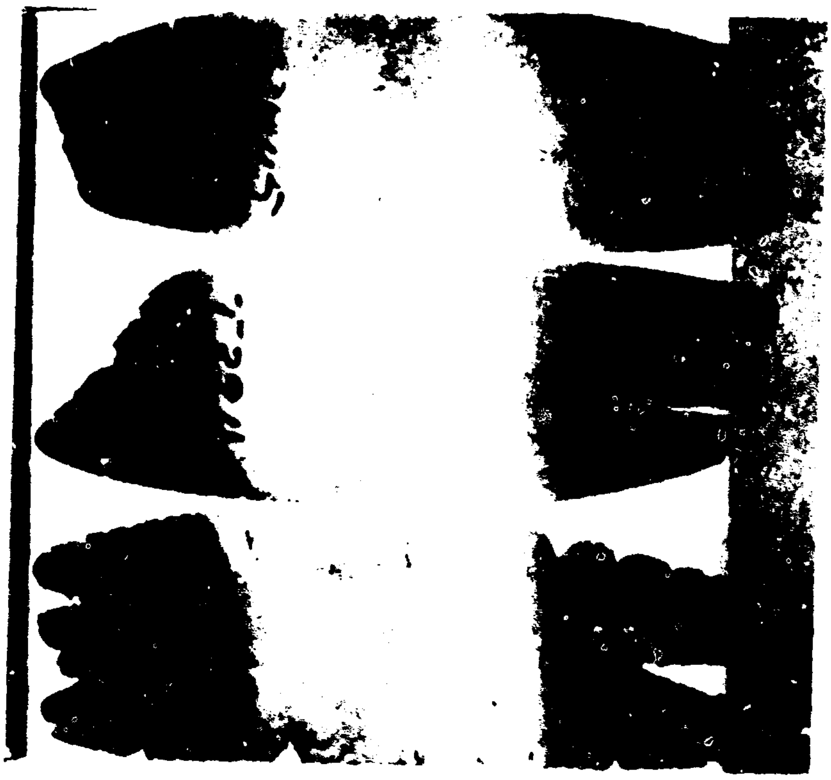
T-3728
Ti-17V-10Cr-3Al-5Cu
Fair Quality

T-3814
Ti-8V-8Mo-7.5Fe-3Al-1Cu
Fair Quality

T-3815
Ti-8Mo-8V-7.5Fe-3Al-3Cu
Poor Quality

T-3816
Ti-8Mo-8V-7.5Fe-3Al-5Cu
Unworkable

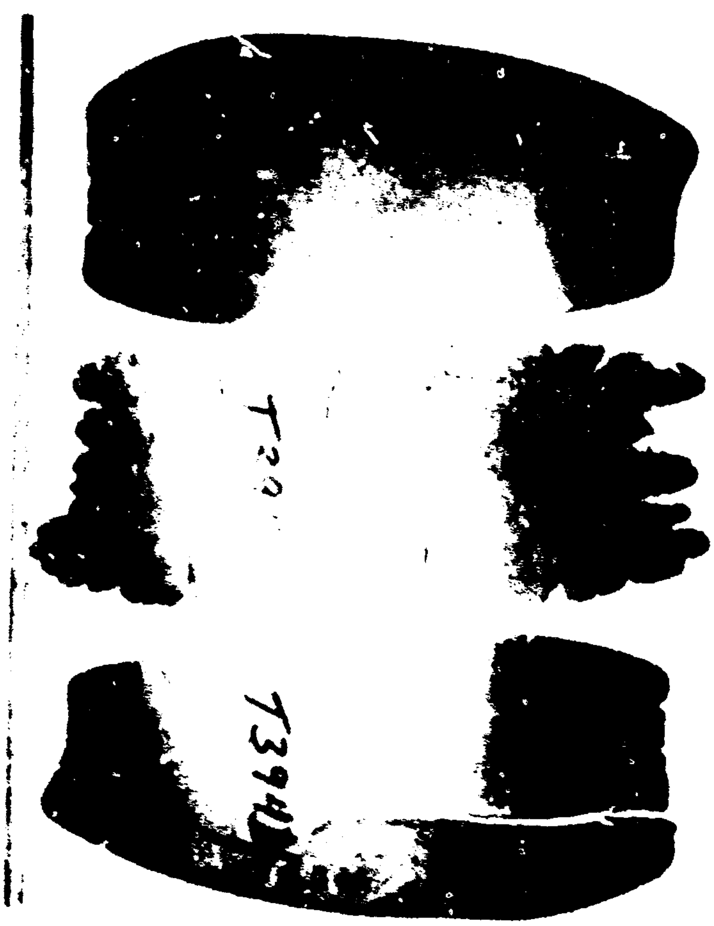
Figure 20. Appearance of Experimental Titanium Alloy Sheet After Hot Rolling to 0.080-Inch Gage and Cold Rolling to 0.050-Inch Gage.



T-3945
Ti-17V-10Cr-3Al-0.1Be
Good Quality

T-3946
Ti-17V-10Cr-3Al-0.2Be
Fair Quality

T-3947
Ti-17V-10Cr-3Al-0.3Be
Poor Quality

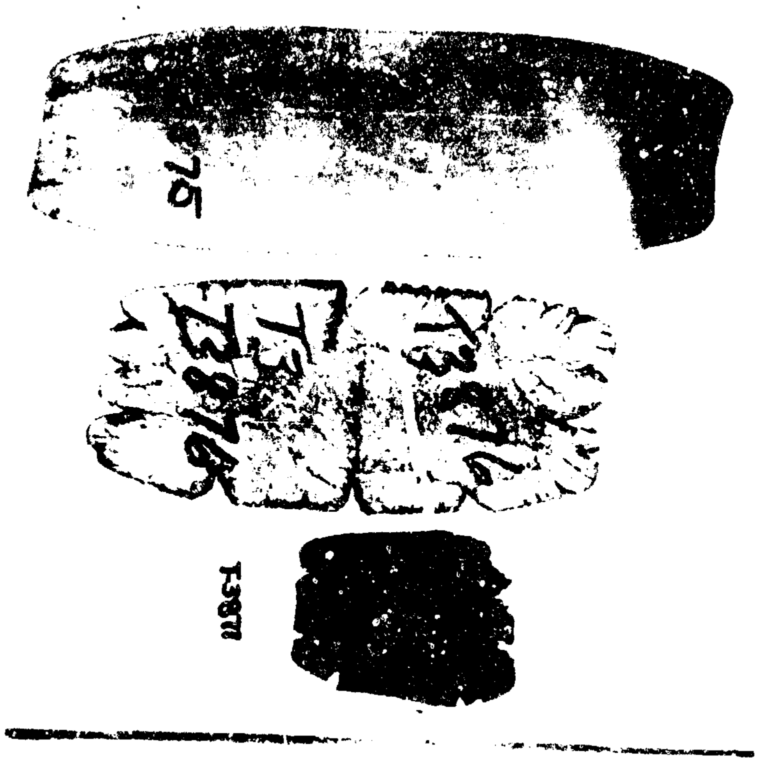


T-3942
Ti-17V-8Cr-3Al-5Cu
Good Quality

T-3943
Ti-17V-7Cr-3Al-5Ni
Poor Quality

T-3944
Ti-17V-7Cr-3Al-5Co
Fair Quality

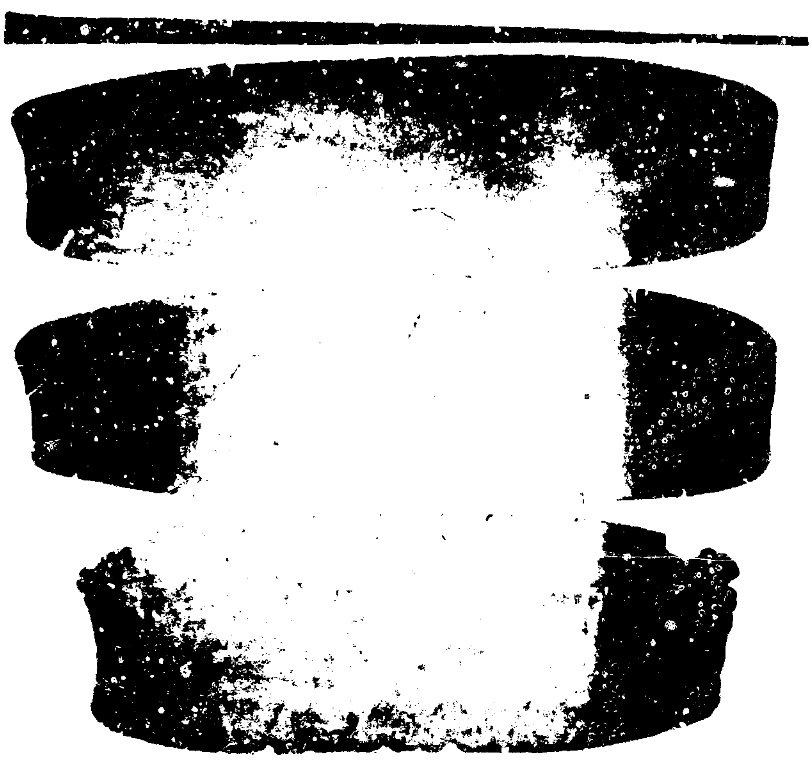
Figure 21. Appearance of Experimental Titanium Alloy Sheet After Hot Rolling to 0.080-Inch Gage and Cold Rolling to 0.050-Inch Gage.



T-3875
Ti-15Mo-5Fe-3Al-1Cu
Good Quality

T-3876
Ti-15Mo-5Fe-3Al-3Cu
Poor Quality

T-3877
Ti-15Mo-5Fe-3Al-5Cu
Unworkable

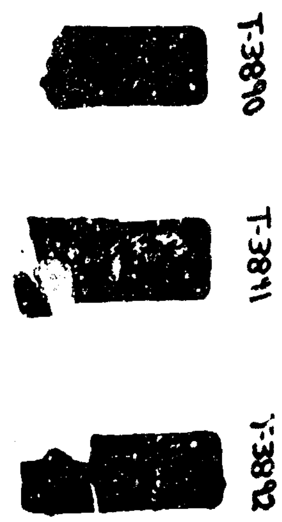


T-3735
Ti-17V-10Cr-3Al-0.5Si
Fair Quality

T-3736
Ti-17V-10Cr-3Al-1Si
Fair Quality

T-3737
Ti-17V-10Cr-3Al-2Si
Fair Quality

Figure 22. Appearance of Experimental Titanium Alloy Sheet After Hot Rolling to 0.080-Inch Gage and Cold Rolling to 0.050-Inch Gage.



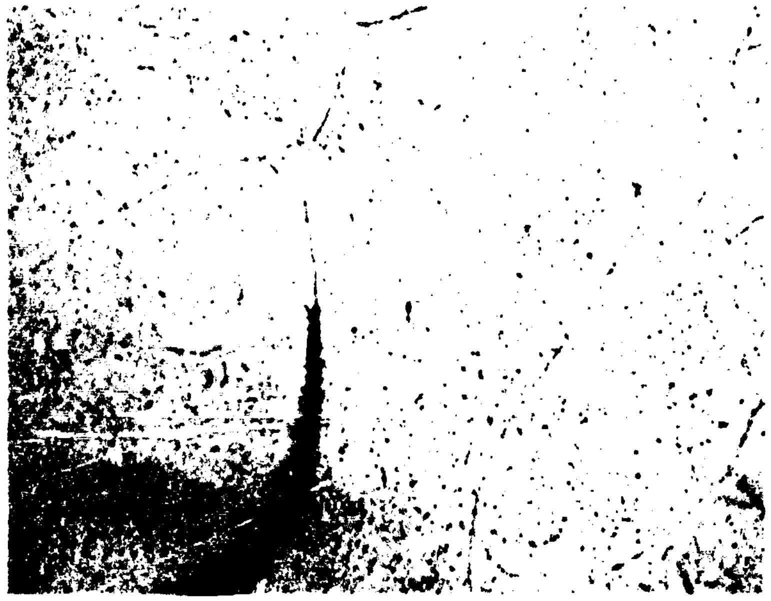
T-3890
Ti-15Mo-5Fe-3Al-1Misch Metal

T-3891
Ti-15Mo-5Fe-3Al-2Misch Metal

T-3892
Ti-15Mo-5Fe-3Al-3Misch Metal

All Unworkable

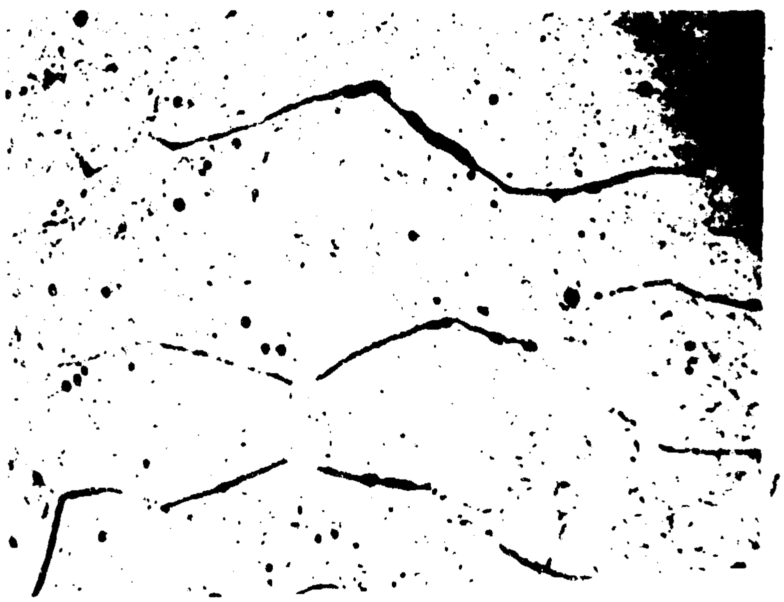
Figure 23. Appearance of Experimental Titanium Alloys After Attempted Hot Rolling To Sheet.



5426 150X

Oxalic+Kroll Etch

Figure 24A. T-3731, Ti-17V-10Cr-3Al-5Ni, Cracking Along Grain Boundaries During Hot Rolling.



5461 100X

Oxalic+Kroll Etch

Figure 24B. T-3882, Ti-15Mo-5Fe-3Al-3Co, Cracking Along Grain Boundaries During Hot Rolling. Considerable Porosity Also Evident In Sample.

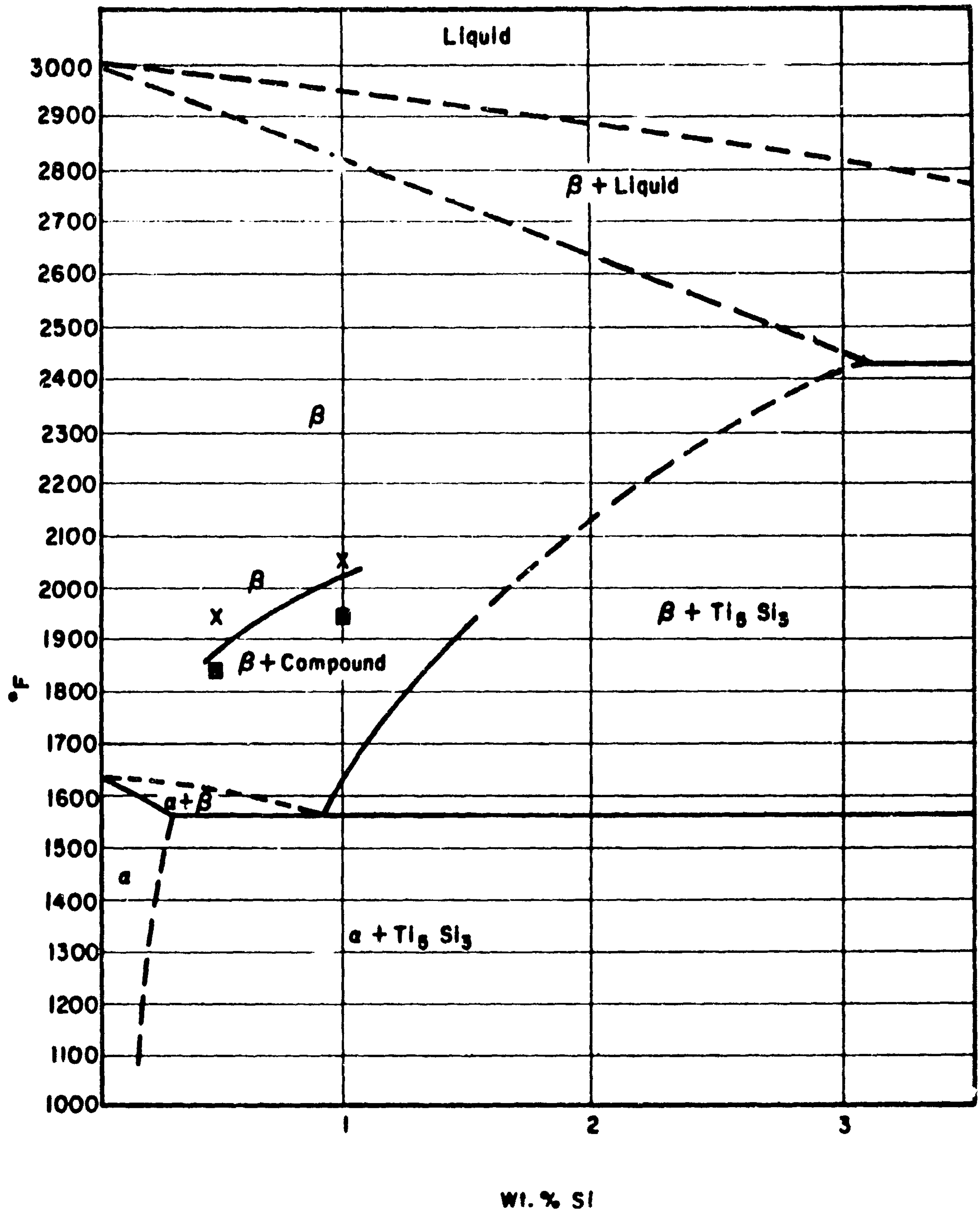


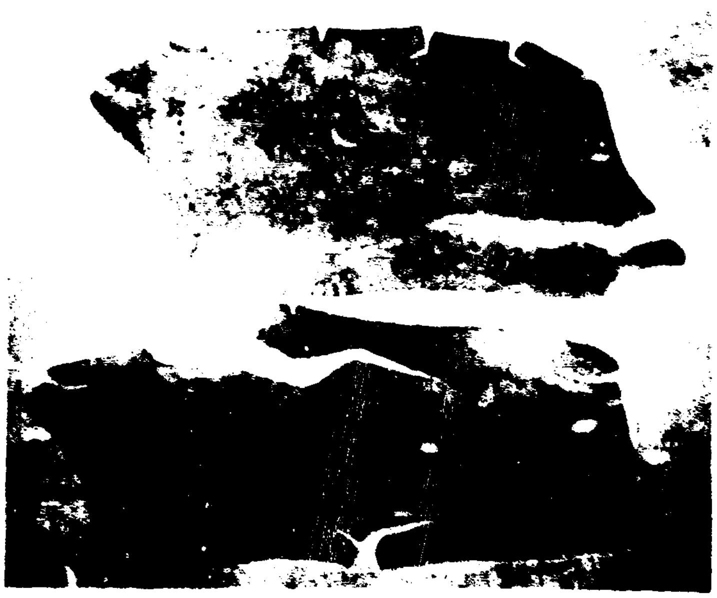
FIGURE 25. THE TITANIUM-SILICON SYSTEM TO 3% Si WITH SUPERIMPOSED β/β+COMPOUND BOUNDARY FOR Ti-17V-10Cr-3Al (0.5-1)Si ALLOYS.

T-4669
Ti-8Mo-8V-6Fe-3Al

T-4670
Ti-8Mo-8V-6Fe-3Al

T-4673
Ti-17V-11Mn-3Al

T-4674
Ti-17V-11Mn-3Al



T-4675
Ti-17V-12Mn-3Al

T-4676
Ti-17V-12Mn-3Al

Figure 26. Appearance of Stable-Beta Alloy Sheets After Cold Rolling From 0.080-Inch to 0.050-Inch.

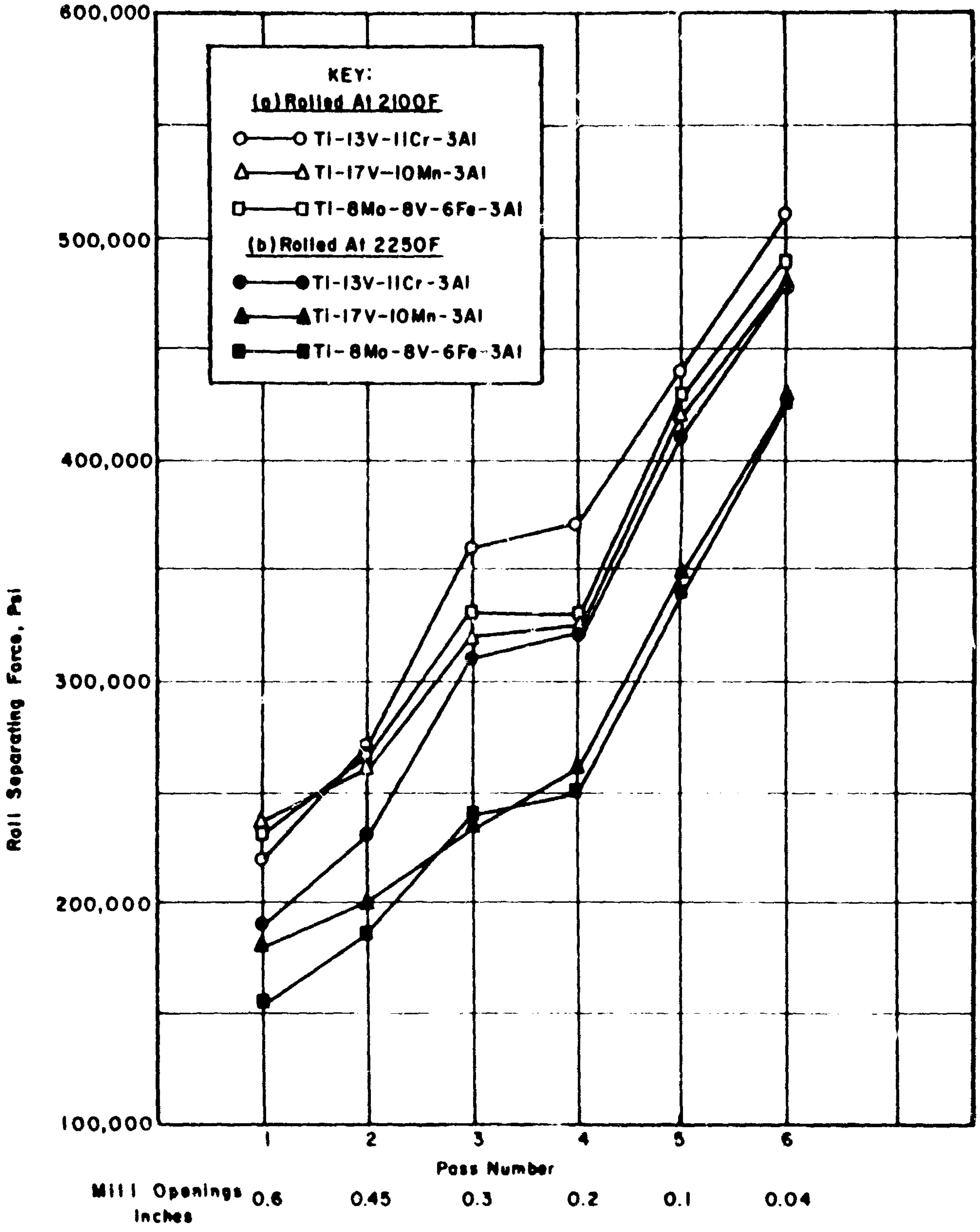


FIGURE 27. ROLL SEPARATING FORCE FOR EXPERIMENTAL STABLE BETA ALLOYS COMPARED WITH THAT OF Ti-13V-11Cr-3Al, METASTABLE BETA COMMERCIAL SHEET ALLOY.

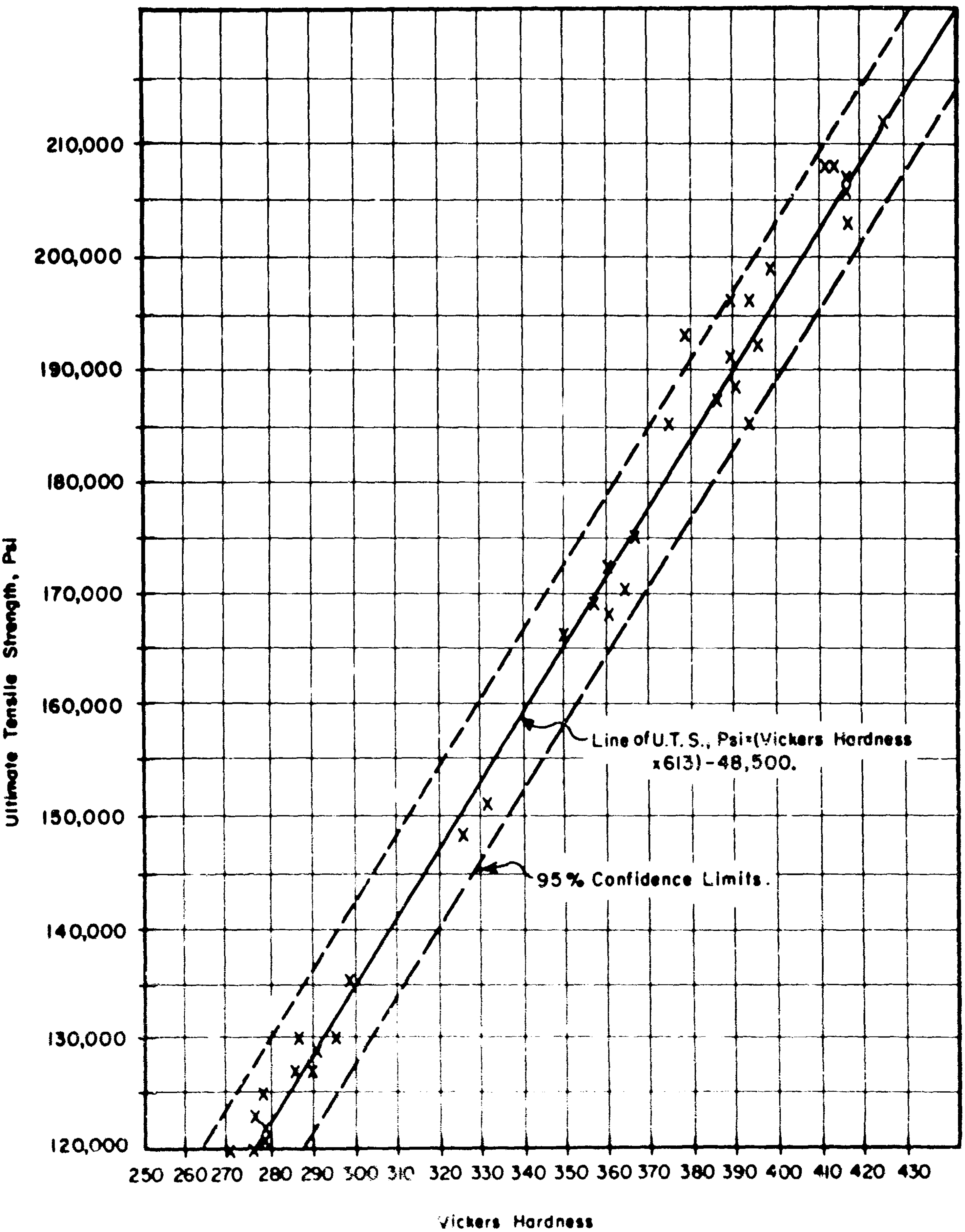


FIGURE 28. STATISTICAL RELATIONSHIP BETWEEN VICKERS HARDNESS AND ULTIMATE TENSILE STRENGTH FOR Ti-8Mo-8V-2Fe-3Al.

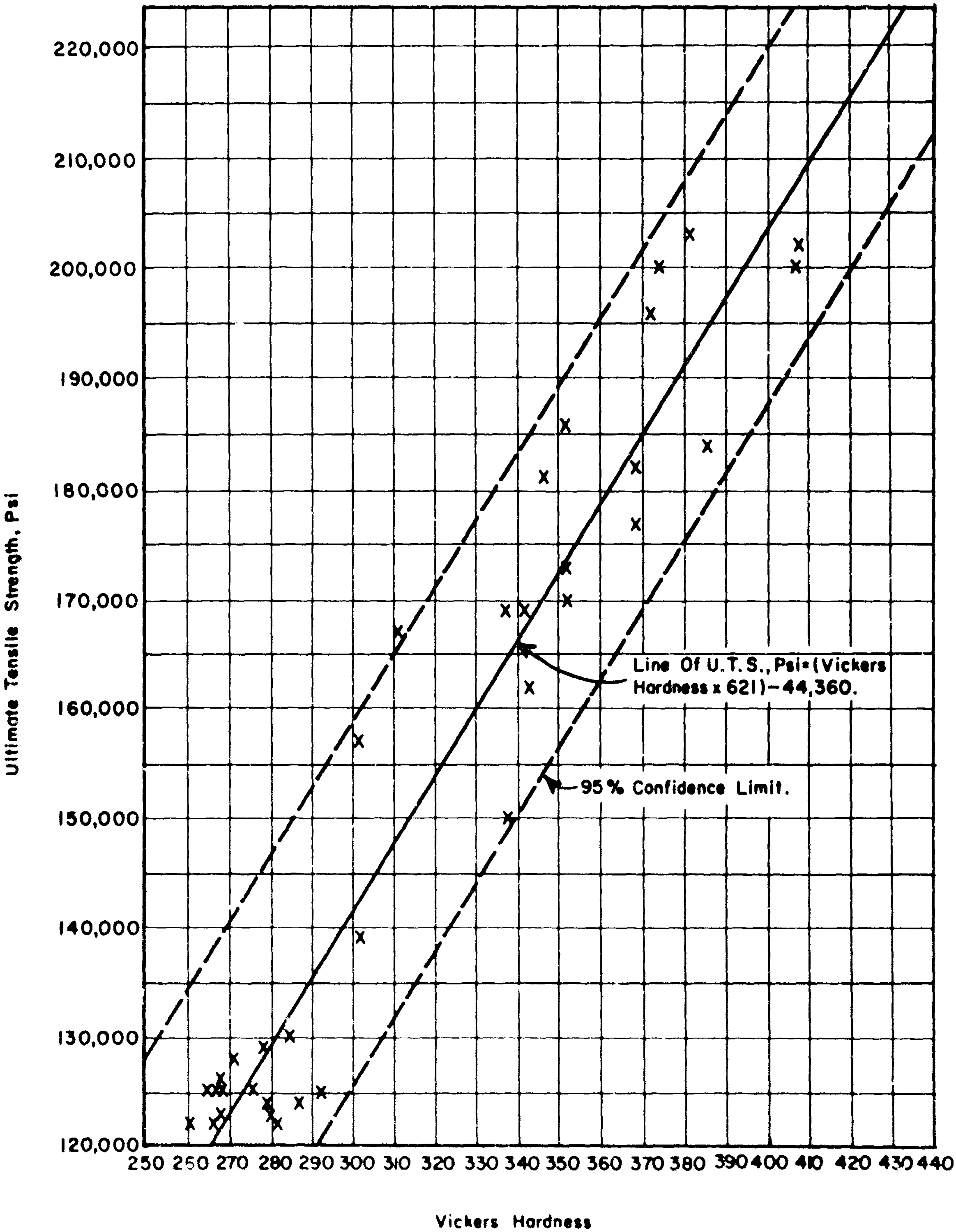


FIGURE 29. STATISTICAL RELATIONSHIP BETWEEN VICKERS HARDNESS AND ULTIMATE TENSILE STRENGTH FOR Ti-17V-4Fe-3Al.

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13. ABSTRACT Research consisted of addition of eutectoid forming elements Fe, Cr and Mn to bases Ti-17V-3Al, Ti-8Mo-8V-3Al & Ti-15Mo-3Al, to produce stable beta bases. Three such alloys were selected as being suitable for addition of elements designed to bring about precipitation hardening: Ti-17V-10Cr-3Al, Ti-8Mo-8V-7.5Fe-3Al and Ti-15Mo-5Fe-3Al. Additions of Cu, Co, Ni, Si, Fe, Be, and rare earths were then made to the above bases in increasing amounts to bring about precipitation hardening. However, fabrication criteria became marginal before enough of the above elements could be added to bring about precipitation hardening. As an exception, addition of 0.5-1%Si to Ti-17V-10Cr-3Al followed by water quenching from solution temperatures of around 2000F and aging at 1150-1250F, produced Vickers hardness increases of up to 100 points upon aging without visible microstructural change. Although precipitation hardening of a stable beta alloy was thus achieved, grain growth and embrittlement were encountered because of the high temperatures required to dissolve the silicide. Work was then redirected toward development of two other types of alloy: a moderate strength stable beta alloy, and a high strength metastable beta alloy hardenable by alpha precipitation. Two stable beta alloys, Ti-17V-10Mn-3Al and Ti-8Mo-8V-6Fe-3Al, and two metastable beta alloys, Ti-17V-4Fe-3Al & Ti-8Mo-8V-2Fe-3Al were evaluated. However, the stable beta alloys had brittle welds, and work on these was discontinued. They were replaced by "stabilized" alloys, metastable alloys aged at 1100-1200F to suppress the maximum aging response and reach a strength plateau. Four such alloys - Ti-8Mo-8V-5Co-3Al, Ti-17V-7.5Co-3Al, Ti-17V-2Fe-2Co-3Al & Ti-8Mo-8V-2Fe-3Al - were evaluated in this condition. Ti-8Mo-8V-2Fe-3Al proved to be best of the high strength metastable beta candidates. On a basis of smooth & notched tensile properties at room temperature and 600F, creep stability & stress corrosion resistance, Ti-8Mo-8V-2Fe-3Al was selected for mill production.

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Alloys, titanium						

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